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AERONAUTICAL RESEARCH LABORATORY

MELBOURNE, VICTORIA

Flight Mechanics Technical Memorandum 408

INCORPORATION OF VORTEX LINE AND VORTEX RING HOVER WAKE MODELS INTO A COMPREHENSIVE ROTORCRAFT ANALYSIS CODE (U)

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SUMMARY

The incorporation of simplified hover wake models into the comprehensive rotorcraft analysis code CAMRAD is described and examples are given on their use. The axisymmetric models, in which vortices are represented by either straight lines or rings, are a more generalized form of the free wake models of R. T. Miller at MIT, with the wake geometry also able to be prescribed. Incorporation has allowed access to the tabular representation in CAMRAD of airfoil section characteristics as functions of angle of attack and Mach number, and has broadened the range of rotor wake models in the code to include a free wake hover model that does not have the convergence problems of the existing free wake model when used for hover.

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CONTENTS

NOTATION*

c	blade chord **
c_ℓ	blade lift coefficient **
C_T/σ	ratio of thrust coefficient to rotor solidity
d_{bv}	core burst test parameter
f	factor introducing lag in solution
f_Γ	empirical scale factor for concentrated vortices inboard of tip vortex
K_1, K_2	axial settling rates of tip vortex before and after passage of following blade
K_3, K_4	radial contraction parameters for tip vortex
M	number of aerodynamic segments
M_{tip}	blade tip Mach number
N	number of blades
r, z	radial and axial displacement coordinates (origin at rotor hub centre; z positive down)
$r_A[i]$	r at mid-points of aerodynamic segments, for i = 1,... M
$r_{AE}[i]$	r at edges of aerodynamic segments (from root to tip), for i = 1,... M+1
r_{bc}	burst vortex core radius
r_c	vortex core radius
r_c'	vortex core radius limited to a minimum of 0.005
r_{uc}	unburst vortex core radius
S	number of concentrated vortices along the blade
T	number of vortex line or ring levels in intermediate wake
u, w	net radial and axial induced velocity components †
u_F, w_F	radial and axial induced velocity components due to far wake †
u_I, w_I	radial and axial induced velocity components due to intermediate wake †
w_b	downwash at blade due to trailing near wake **
w_{self}	self-induced downwash at blade **
α	blade angle of attack **
Γ	blade bound circulation **
Δ	incremental change in appropriate quantity
ε	tolerance for induced velocity convergence
θ	blade pitch angle **
λ_x, λ_y, λ_z	longitudinal, lateral, and vertical induced velocity components (funct's of r, ψ)
ϕ	blade inflow angle **
ψ	blade azimuth angle

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* All quantities are dimensionless (based on density, rotor rotational speed, and rotor radius). Quantities used only locally to simplify expressions are not included here

** Function of r

† Function of r, z

Subscripts

m,n — as for subscipt (s,t) but at a source of induced velocity, i.e. when calculating induced velocity at $(r_{s,t}, z_{s,t})$, contributions are summed over (m,n)

max — maximum value

new — value at current iteration

old — value at previous iteration

s,t — value at concentrated vortex number s (from tip), where $1 \leq s \leq S$, and at vortex line or ring level number t at which induced velocity is to be calculated (i.e. object). Note: $1 \leq s \leq S$ and $1 \leq t \leq T$ in intermediate wake; $t = 0$ at blade, in which case subscript is dropped (e.g. $r_{s,0} \equiv r_s$); $t = T + 1$ for far wake

1. INTRODUCTION

In response to requests from the Australian Services to evaluate performance characteristics, especially for hover, of helicopters presently operated, as well as those being considered for procurement, Aeronautical Research Laboratory (ARL) has developed an analysis capability in the area of hovering rotor aerodynamics which includes both inhouse and acquired codes .

In 1987, Reddy and Gilbert compared predicted hover performance with flight data for four helicopters.[1] Comparisons were also made of main rotor blade loading distribution for one of the helicopters, a Sikorsky S-58 (equivalent to Westland Wessex). Predictions were obtained using three nonuniform inflow rotor wake models and a uniform inflow model based on momentum theory. The nonuniform wake models used were a

- helical vortex lattice prescribed wake model,
- vortex line prescribed wake model, and
- vortex ring free wake model.

The first of these models is incorporated in CAMRAD (Comprehensive Analytical Model of Rotorcraft Aerodynamics and Dynamics), a code developed by Johnson at Ames Research Center.[2,3,4,5] The code, which was acquired in 1984 as part of a cooperative program with the US Army, uses straight-line vortex elements joined in the form of a helical vortex lattice to represent the trailed and shed vorticity. CAMRAD was also used to provide uniform inflow predictions (based on momentum theory), a preliminary process in determining the trimmed prescribed wake solution.

The second model, which uses infinite and semi-infinite straight-line vortices, was developed by Reddy [6,7] at ARL independently of very similar work by Miller [8,9] at Massachusetts Institute of Technology (MIT) and Beddoes (unpublished) at Westland Helicopters Limited (WHL). An acquired free wake hover code that was implemented at ARL by Hill and Reddy(unpublished) was used as the third model. The method, which generally represents infinite line vortices by rings, is based on one of the variations in Miller's method.

To investigate the consistency of these methods, the same parameters and empirical corrections were used within each model in applying to each helicopter, and where possible, consistency of appropriate quantities between models was also maintained. The major identified inconsistency between the wake models was the different representation of airfoil characteristics. In CAMRAD, the two-dimensional airfoil section characteristics are represented in tabular form as functions of angle of attack and Mach number; compressibility effects are therefore effectively incorporated. In the more simplified vortex line and vortex ring models, the characteristics are represented by a constant lift curve slope and a quadratic drag polar without corrections for compressibility. It was planned therefore to incorporate the vortex line and vortex ring models into CAMRAD, principally to allow the two-dimensional airfoil data to be available to these simpler models.

Since Miller's models are formulated in a way that allows a free wake geometry for both the vortex line and vortex ring models, it was decided to incorporate his models, but in a more generalized form, allowing the geometry to also be prescribed using the options in CAMRAD, as well as some additional features. The main purpose of this report is to document the model formulation used and to provide the information necessary to run the models.

2. WAKE MODELS

Comprehensive codes such as CAMRAD allow the analysis of a complete rotorcraft, usually allowing for two separate rotors. However, it is generally assumed sufficient to consider only the main rotor in the case of hover for a conventional helicopter with a single main rotor and anti-torque tail rotor. For performance predictions, standard estimates are then made for the power requirements of the tail rotor, accessories and transmission, and aerodynamic interference. By assuming an axisymmetric wake, the harmonics of blade motion and the shed wake can be neglected, and only collective control needs to be adjusted to trim to a specified thrust.

The helical vortex lattice model in CAMRAD follows the common approach of closely tracing the three-dimensional helical shape of both the strong tip vortex and inboard vortex sheet. Unfortunately, this apparently straight-forward approach results in a computation process that is complex and computationally demanding. This is especially so for the hover case where there is no large uniform relative wind due to the translational velocity of the helicopter. This means that the wake is not swept away from the rotor and hence more of the wake must be considered. It also means that wake induced velocities are the only velocities present, resulting in a greater sensitivity of the wake geometry to changes in induced velocity. This increased sensitivity leads to instabilities and slow wake convergence if free wake models are used.[10]

The simplified axisymmetric methods described here are an attempt to overcome the above problems for the hover case. The basis of these methods is that the continuously descending helix is represented by vertically separated horizontal vortex lines (for a horizontal rotor disc), which are either straight or circular. The wake is divided into three regions, which are defined as near, intermediate, and far.

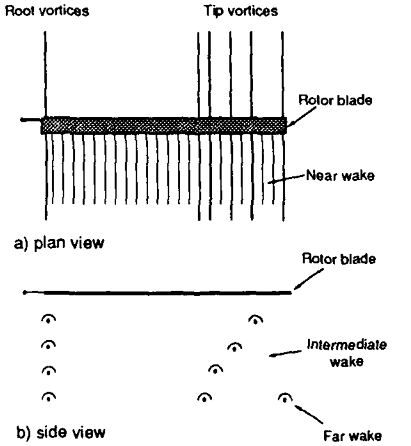

Fig. 1 Vortex Line Wake Model with Concentrated Far Wake

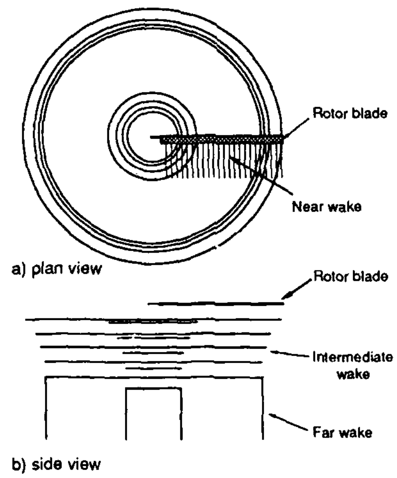

Fig. 2 Vortex Ring Wake Model with Distributed Far Wake

The three wake regions are illustrated in Figs 1 and 2 for the vortex line and vortex ring models respectively. These are first described in relation to a prescribed wake geometry using either of the options in CAMRAD, i.e. (a) Landgrebe[11] or (b) Kocurek and Tangler.[12] Both are based on model rotor flow visualization data.

For both vortex line and vortex ring models, the near wake is represented by semi-infinite straight lines attached to, and in the plane of, the blade, with a greater concentration towards the tip. Based on the observations in Kocurek and Tangler's experiments of four well defined tip vortices below the blade, the intermediate wake is represented at each of the corresponding four axial levels by either two straight infinite vortex lines (Fig. 1) or two vortex rings (Fig. 2). However, the generalized manner in which these methods are implemented here allows the number of these levels to be varied (up to 36). One of these 'concentrated' rolled-up vortices is located at the outside boundary of the prescribed contracted wake and represents the strong tip vortex, and the other is located directly beneath the root cutout and represents the inboard vorticity.

Below the intermediate wake region, it is believed that the wake is unstable; the tip vortices undergo viscous dissipation, resulting in wake expansion. To account for this region, which is still close enough to the rotor disc to induce significant inflow, Kocurek and Tangler proposed a vortex ring with radius equal to the rotor radius, axial location at the same level as the fourth tip vortex beneath the rotor, and strength of four times that of the tip vortex. This concept is adopted as an option for the far wake (referred to as 'concentrated far wake') in the form of either a ring for the vortex ring model, or an infinite straight line replacing the ring for the vortex line model, as shown in Fig. 1. The other option for the far wake included is the one given by Miller (referred to as 'distributed', 'sheet', or 'distributed sheet') using two semi-infinite vortex planes (for vortex line) or cylinders (for vortex ring - as in Fig. 2) with strength determined by the geometry of the intermediate wake, and positioned one wake spacing below each of the last inner and outer rings of the intermediate region. This latter option is the only one used for the free wake method. For the prescribed wake method, the far wake may be neglected.

When the wake geometry is allowed to be free in Miller's simplified models, the difficulties of convergence typical of vortex lattice models are not generally experienced. The radius and axial spacing of each concentrated vortex in the intermediate wake, with its consequent effect on the distributed far wake, is determined by the requirements for equilibrium of the velocities, this being the essence of the free wake method. In Miller's method, up to three concentrated vortices are allowed in the intermediate wake though only two are used in the prescribed intermediate wake here and in Ref. 1 by Reddy and Gilbert when using Miller's vortex ring free wake model. The generalized formulation here allows this number to be increased up to ten.

The computational procedure is outlined in Appendix A, with the prescribed wake method incorporated as part of the complete method, and expressions for the velocity components induced by wake vortex elements are given in Appendix B (see Ref. 8 for derivations). Block diagrams showing the separate structures of the free and prescribed wake methods are given in Appendices C and D respectively.

3. PROGRAM MODIFICATIONS

Modifications to the standard VAX 780 version of CAMRAD are given. Because the new axisymmetric models are intended to be used for a single rotor configuration, modifications made to Rotor 1 subprograms are not similarly made to Rotor 2 subprograms.

The following subprograms (each stored as a separate Fortran file, e.g. GEOMR1.FOR) in CAMRAD (see Ref. 5, Part II) have been modified (see Appendix E):

GEOMR1	-	Calculate wake geometry distortion
INPTW1	-	Read wake namelist
PRNTW1	-	Print wake input data
RAMF	-	Calculate rotor/airframe periodic motion and forces
TRIM	-	Trim
TIMER	-	Program timer

Changes to the VAX VMS operating system since 1984 have resulted in the output of null component CPU times at the end of the CAMRAD output file. Modifications to TIMER, while not necessary for implementation of the models, are therefore included in Appendix E.

The following added subprograms (all included in the file WAKER1.FOR) form the basis of the new models (see Appendix F):

WAKER1	-	Determine induced velocity at rotor using vortex line or ring model
VTXIF	-	Calculate induced velocity in intermediate wake due to intermediate and far wake
IVTERP	-	Calculate induced velocity along blade at concentrated vortices
ILINE	-	Evaluate expressions for velocity induced by vortex line in intermediate wake
IRING	-	Evaluate elliptic integral expressions for velocity induced by vortex ring in intermediate wake
ELLIPCON	-	Calculate constants used in elliptic integral expressions
FRING	-	Evaluate elliptic integral expressions for velocity induced by semi-infinite vortex cylinder in far wake
FLINE	-	Evaluate elliptic integral expressions for velocity induced by semi-infinite vortex sheet in far wake
PRESWG	-	Determine prescribed wake geometry

The above modified files and added file are first compiled. After then obtaining the main program object file CAMRAD.OBJ and library object file CAMRAD.OLB containing all original compiled subprograms, the new executable file CAMRAD.EXE is given on typing

```
$LINK CAMRAD,GEOMR1,INPTW1,PRNTW1,RAMF,TRIM,TIMER,WAKER1,CAMRAD/LIB
```

Nine new input variables, all in namelist NLWAKE, have been added (see Appendix G for description and default values). Also included in Appendix G are some comments on existing CAMRAD variables.

4. TEST CASES

To demonstrate the various model options and illustrate the effect of including compressibility, comparisons are made of blade loading distribution for the S-58 using Scheiman's test data[13] as in Ref. 1. Main rotor performance and blade loads are obtained from CAMRAD using the basic H-34 (i.e. S-58) data deck and NACA 0012 airfoil tables.

Fig. 3 shows the effect of compressibility using the vortex ring, free wake model. Since the tip Mach number is relatively low (= 0.56), the effect is only minimal in this example. For the 'compressible' case in Fig. 3, the command file and resulting output file (the latter in abbreviated form) are given in Appendices H and J respectively . The vortex ring, free wake model is selected by setting OPMODL = 2 and LEVEL(1) = 2. Two rolled-up vortices (NIBV = 2) and four vortex levels in the intermediate wake (NIVL = 4) are specified. The free wake model only allows the distributed sheet far wake mode!. The empirical factor scaling the rolled-up concentrated vortices inboard of the one at the tip is set to the default value of 0.6. By setting inputs DEBUG(14) and DEBUG(24) to 1, additional information on the induced velocity and free wake geometry is printed. Because the solution is independent of azimuth, the number of azimuth steps per revolution (MPSI and also MPSIR) is set to the minimum value of 4, the number of blades.

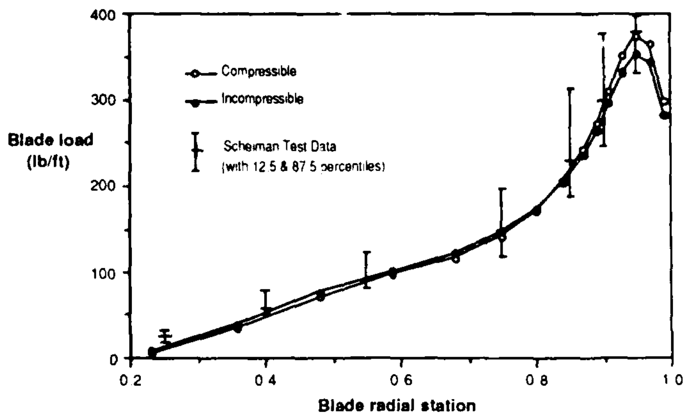

Fig. 3 Effect of Compressibility on Blade Load Distribution for S-58 using Vortex Ring, Free Wake Model (C_T/σ = 0.0817)

Operating conditions and main rotor data, which are common to all the test cases presented, are included in the output file listing (Appendix J). Values of the new input variables for the new models are included in the 'Main Rotor' subsection of the 'Input Data' section of this file.

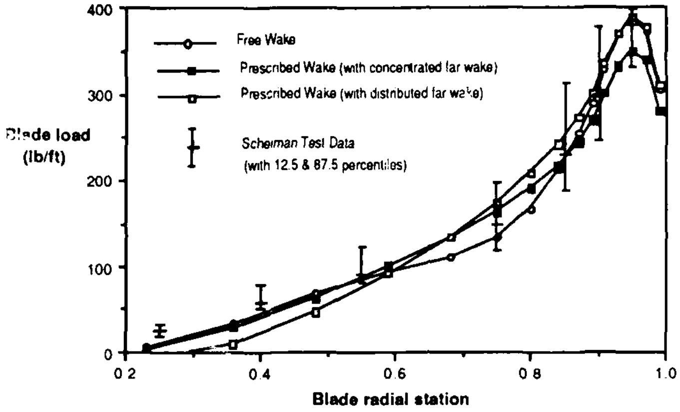

Fig. 4 Effect of Wake Model Variations on Blade Load Distribution for S-58 using Vortex Line Model (C_T/σ = 0.0817)

Figs 4 and 5 show the effect of the same wake model variations applied to the vortex line and vortex ring models respectively, each with compressibility included. In Table 1, the maximum blade loading (at a radial station of 0.95) is tabulated for these variations, but both with and without compressibility included. Each model gives reasonably similar distributions, but the maximum loading given by the vortex line, prescribed wake model with a concentrated far wake is about 10% less than that given by the other models.

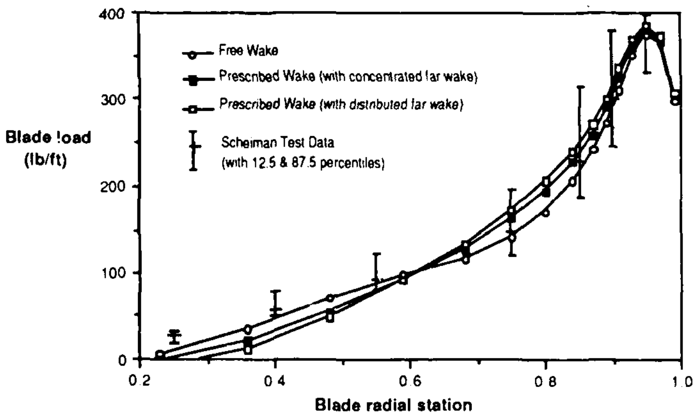

Fig. 5 Effect of Wake Model Variations on Blade Load Distribution for S-58 using Vortex Ring Model (C_T/σ = 0.0317)

TABLE 1
Effect of Wake Model Options on Maximum Blade Load for S-58

Wake Model	Compressible		Incompressible	
	Vortex Line	Vortex Ring	Vortex Line	Vortex Ring
Free	388	375	365	353
Prescribed (concentrated far wake)	349	380	316	338
Prescribed (distributed far wake)	388	385	346	346

5. CONCLUDING REMARKS

By incorporating the simplified hover wake models described here into CAMRAD, the models themselves have been enhanced by allowing access to compressibility effects included in the two-dimensional airfoil tables used by CAMRAD. In addition, the range of rotor wake models in CAMRAD has been broadened and now includes a free wake hover model (either vortex line or vortex ring) that does not have the convergence problems of the existing free wake model in CAMRAD when used for hover.

In deciding which of the simplified models to use, consideration should be given to maintaining a balance between the degrees of approximation used within the wake model itself. Specifically, when representing vortices by just straight lines in all wake regions, the added complexity of a free wake solution may not be warranted. The more physically accurate representation by rings would therefore seem to be more consistent with a free wake.

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APPENDIX A
Computational Procedure

Initial Step - Free Wake only

For $r = r_A[i]$ at $i = 1,...M$, set

$$w(r) = \lambda_z(r)$$
$$u(r) = 0$$

where

r = radial displacement coordinate along the blade

$r_A[i]$ = r at mid-points of aerodynamic segments

M = number of aerodynamic segments

u, w = net radial and axial induced velocity components

λ_z = vertical component of induced velocity, given by uniform inflow method based on momentum theory (from CAMRAD)

Iteration Loop

STEP 1 - Free Wake only

Calculate bound circulation distribution $\Gamma(r)$ along the blade for $r = r_A[i]$ at $i = 1,...M$:

$$\Gamma(r) = \frac{1}{2} r \; c(r) \; c_\ell (r, \alpha, r M_{tip})$$

where

c = blade chord

c_ℓ = blade lift coefficient

The latter is interpolated from 2-D airfoil tables as a function of angle of attack α and Mach number $r M_{tip}$, with α given by

$$\alpha(r) = \theta(r) - \phi(r)$$

where

$\theta(r)$ = blade pitch angle (specified)

$\phi(r)$ = blade inflow angle (= $w(r)/r$)

STEP 2

Representing the near wake by semi-infinite line vortices at $r = r_{AE}[i]$ for $i = 1,...M+1$, calculate, using the Biot-Savart law, the induced velocity $w_b(r)$ along the blade at $r = r_A[i]$ for $i = 1,...M$:

$$w_b(r) = -\sum_{i=1}^{M+1}\left[\frac{\Delta\Gamma(r_{AE}[i])}{4\pi}\left(\frac{1}{r_{AE}[i] - r} + \frac{1}{r_{AE}[i] + r}\right)\right]$$

where

$$\Delta\Gamma(r_{AE}[i]) = \Gamma(r_A[i]) - \Gamma(r_A[i-1]) \qquad \text{for } i = 2,...M$$

$$\Delta\Gamma(r_{AE}[1]) = \Gamma(r_A[1])$$

$$\Delta\Gamma(r_{AE}[M+1]) = -\Gamma(r_A[M])$$

The above bound circulation distribution is given in Step 1 for the free wake, and by the uniform inflow method based on momentum theory (from CAMRAD) for the prescribed wake.

STEP 3

Determine the circulation strength Γ_s and location r_s of each rolled-up, concentrated vortex along the blade for $s = 1,...S$ (tip to root), where S is the total number of these vortices. The boundaries for each region to be represented by concentrated vortices are first defined as follows.

The outboard boundary of the tip vortex region is at $r_{AE}[M_0]$, where $M_0 = M + 1$, and the inboard boundary is at $r_{AE}[M_1]$, where $\Gamma(r_A[M_1])$ is the maximum of the circulation strengths (Γ_{max}) calculated in Step 1 along the blade at the aerodynamic segment mid-points.

The boundaries for the inboard regions are defined to be at the closest aerodynamic segment boundary inboard of the values defined by the user. The array indices are defined as $M_2,...M_{S-1}$, corresponding to boundaries $r_{AE}[M_2],...r_{AE}[M_{S-1}]$. The most inboard boundary is at the blade root, where the index is M_S, and the boundary $r_{AE}[M_S]$.

a) Free Wake

The circulation strength Γ_s and location r_s (centroid of circulation distribution over the region $r_{AE}[M_s]$ to $r_{AE}[M_{s-1}]$) are given by

$$\Gamma_s = -\sum_{i=M_s}^{M_{s-1}} \Delta\Gamma(r_{AE}[i])$$

$$r_s = \frac{1}{\Gamma_s}\sum_{i=M_s}^{M_{s-1}} r_{AE}[i]\,\Delta\Gamma(r_{AE}[i])$$

For $s = 2,...S$, Γ_s is then scaled by an empirical factor f_Γ (default value of 0.6).

b) Prescribed Wake

Here S = 2, and the concentrated vortices are assumed to be at the boundary extremities (tip and root), with the magnitude of the circulation strength of each equal to Γ_{max}, i.e.

$$\Gamma_1 = \Gamma_{max} \qquad \Gamma_2 = -\Gamma_{max}$$

$$r_1 = r_{AE}[M+1] \qquad r_2 = r_{AE}[1]$$

STEP 4 - Free Wake only

By interpolating induced velocity components along the blade calculated at the previous iteration in Step 8 (zero initially), determine values at each concentrated vortex position, for $s = 1,...S$:

$$\{u_I\}_s = u_I \quad \text{at } r = r_s$$
$$= u_I(r_A[i-1]) + (u_I(r_A[i]) - u_I(r_A[i-1]))\left[\frac{r_s - r_A[i-1]}{r_A[i] - r_A[i-1]}\right] \quad \text{for } r_A[i-1] < r_s < r_A[i]$$

and similarly for $\{w_I\}_s$, $\{u_F\}_s$, and $\{w_F\}_s$.

STEP 5 - Free Wake only

Set intermediate wake geometry, defining radial and axial positions of the concentrated vortices at each vortex line or ring level, i.e. $r_{s,t}$ and $z_{s,t}$, for $s = 1,...S$ and $t = 1,...T$, where T is the number of levels:

$$r_{s,t} = r_{s,t-1} + \Delta r_{s,t}$$

$$z_{s,t} = z_{s,t-1} + \Delta z_{s,t}$$

where the incremental displacements $\Delta r_{s,t}$ and $\Delta z_{s,t}$ are given from the previous iteration (Step 13), but are approximated initially by

$$\Delta r_{s,t} = 0$$

$$\Delta z_{s,t} = \frac{2\pi}{N}\lambda_z(r_A[M])$$

STEP 6 - Free Wake only

Calculate radial and axial components of the induced velocity at each vortex position in the intermediate wake, i.e. for $s = 1,...S$ and $t = 1,...T$, (a) due to the intermediate wake to give $\{u_I\}_{s,t}$ and $\{w_I\}_{s,t}$, and (b) due to the far wake to give $\{u_F\}_{s,t}$ and $\{w_F\}_{s,t}$. Only the radial components are shown below; the axial components are given by substituting w for u in all expressions:

$$\{u_I\}_{s,t} = \sum_{m=1\ (\neq s)}^{S} \ \sum_{n=1\ (\neq t)}^{T} u_I(r_{s,t},\ r_{m,n},\ z_{m,n} - z_{s,t},\ \Gamma_m)$$

$$\{u_F\}_{s,t} = \sum_{m=1\ (\neq s)}^{S} \frac{1}{\Delta z_{m,T}} u_F(r_{s,t},\ r_{m,T+1},\ z_{m,T+1} - z_{s,t},\ \Gamma_m)$$

Expressions for the above right-hand side velocity components, together with equivalent axial components, are given in Appendix B for both vortex line and vortex ring models.

STEP 7 - Free Wake only

Using the Biot-Savart law as in Step 2, calculate the induced velocity $\{w_b\}_s$ at concentrated vortices on the blade due to the trailing near wake for $s = 1,...S$:

$$\{w_b\}_s = w_b(r) \quad \text{at } r = r_s$$

$$= \sum_{m=1\ (\neq s)}^{S} \frac{\Gamma_m}{4\pi}\left(\frac{1}{r_m - r_s}\right) + \sum_{m=1\ (\neq s)}^{S} \frac{\Gamma_m}{4\pi}\left(\frac{1}{r_m + r_s}\right)$$

STEP 8 - Free Wake only

Determine net radial and axial components of the induced velocity at concentrated vortex positions on the blade (i.e. at $t = 0$) and at each vortex position in the intermediate wake:

$$u_{s,t} = \{u_I + u_F\}_s \qquad \text{for } t = 0$$

$$= \{u_I + u_F\}_{s,t} \qquad \text{for } t = 1,...T$$

$$w_{s,t} = \{w_I + w_F + w_b\}_s + \{w_{self}\}_s \qquad \text{for } t = 0$$

$$= \{w_I + w_F\}_{s,t} + \{w_{self}\}_s \qquad \text{for } t = 1,...T$$

The self induced velocity $\{w_{self}\}_s$ of a vortex ring of radius r_s is given by

$$\{w_{self}\}_s = \frac{\Gamma_s}{4\pi}\left[\ell n\left(\frac{8r_s}{r_c'}\right) - \frac{1}{4}\right]$$

where

r_c' = vortex core radius r_c limited to a minimum of 0.005, i.e.max(0.005, r_c)

r_c = r_{bc} (burst vortex core radius) if $d_{bv} \geq 0$ or $z_{1,1} < d_{bv}$

= r_{uc} (unburst vortex core radius) otherwise

d_{bv} = core burst test parameter (< 0 to suppress bursting) - from CAMRAD

STEP 9

a) Free Wake

Using net induced velocity components at the blade and in the intermediate wake, determine new wake geometry for s = 1,...S and t = 1,...T:

$$r_{s,t} = r_{s,t-1} + \Delta r_{s,t}$$

$$z_{s,t} = z_{s,t-1} + \Delta z_{s,t}$$

where the incremental displacements $\Delta r_{s,t}$ and $\Delta z_{s,t}$ are given by

$$\Delta r_{s,t} = \frac{\pi(u_{s,t-1} + u_{s,t})}{N}$$

$$\Delta z_{s,t} = \frac{\pi(w_{s,t-1} + w_{s,t})}{N}$$

b) Prescribed Wake

Using prescribed wake geometry based on either of the options in CAMRAD, i.e. (a) Landgrebe or (b) Kocurek and Tangler, set tip and root vortex positions (noting S = 2) for t = 1,...T:

$$r_{1,t} = K_4 + (1 - K_4)\, e^{-2\pi K_3 t/N}$$

$$r_{2,t} = r_{AE}[1]$$

$$z_{1,t} = z_{2,t} = -\frac{2\pi}{N}\left[K_1 + K_2(t-1)\right]$$

where

K_1, K_2 = axial settling rates of tip vortex before and after passage of following blade

K_3, K_4 = radial contraction parameters for tip vortex

These parameters are given by CAMRAD on specifying the appropriate option, i.e. value of OPRWG in Namelist NLWAKE.

STEP 10

Calculate radial and axial components of the induced velocity along the blade (a) due to the intermediate wake to give $u_I(r)$ and $w_I(r)$, and (b) due to the far wake to give $u_F(r)$ and $w_F(r)$ for $r = r_A[i]$ at i = 1,...M. As in Step 6, only the radial components are shown below, with axial components obtained by substituting w for u:

$$u_I(r) = \sum_{m=1}^{S} \sum_{n=1}^{T} u_1(r, r_{m,n}, z_{m,n}, \Gamma_m) \left(\frac{d^2}{d^2 + r_c'^2}\right)$$

$$u_F(r) = \sum_{m=1}^{S} \frac{1}{\Delta z_{m,T}} u_F(r,\ r_{m,T+1},\ z_{m,T+1},\ \Gamma_m) \qquad \text{for distributed far wake}$$

$$= u_I(r,\ r_1,\ z_{1,T},\ 4\Gamma_1) + u_I(r,\ r_2,\ z_{2,T},\ \Gamma_2) \qquad \text{for concentrated far wake (prescribed only)}$$

where

$$d^2 = (r_{m,n} - r)^2 + (z_{m,n} - z)^2$$

Expressions for the above right-hand side velocity components, together with the equivalent axial components, given in Appendix B are again used.

STEP 11

Determine net radial and axial components of the induced velocity along the blade to give $u(r)$ and $w(r)$ for $r = r_A[i]$ at $i = 1,...M$:

$$u(r) = u_I(r) + u_F(r)$$

$$w(r) = w_I(r) + w_F(r) + w_b(r)$$

For prescribed wake, go to Step 14.

STEP 12 - Free Wake only

Test for convergence of induced velocity; if the maximum number of iterations has been reached or

$$\frac{1}{M}\sum_{i=1}^{M} \left[\{w(r_A[i])\}_{new} - \{w(r_A[i])\}_{old} \right]^2 < \left[\tfrac{1}{2}\, w_{max}\, \varepsilon\right]^2$$

where

$$w_{max} = \max |w(r_A[i])|$$

$$\varepsilon = \text{tolerance for induced velocity convergence}$$

and then go to Step 14.

STEP 13 - Free Wake only

To help prevent numerical instability in the iterative procedure, lag new (non-convergent) solution for (a) induced velocity $u(r)$ and $w(r)$ along the blade for $r = r_A[i]$ at $i = 1,...M$, and (b) wake geometry incremental displacements $\Delta r_{s,t}$ and $\Delta z_{s,t}$ for $s = 1,...S$ and $t = 1,...T$:

$$u(r) = f\,\{u(r)\}_{new} + (1 - f)\,\{u(r)\}_{old}$$

$$w(r) = f\,\{w(r)\}_{new} + (1 - f)\,\{w(r)\}_{old}$$

$$\Delta r_{s,t} = f\,\{\Delta r_{s,t}\}_{new} + (1 - f)\,\{\Delta r_{s,t}\}_{old}$$

$$\Delta z_{s,t} = f\,\{\Delta r_{s,t}\}_{new} + (1 - f)\,\{\Delta z_{s,t}\}_{old}$$

where the factor f used to introduce lag into the solution is typically 0.1.

Having completed an iterative cycle for the free wake, go back to Step 1.

STEP 14

Transform induced velocity components u(r) and w(r) along the blade to longitudinal, lateral, and vertical components $\lambda_x(r, \psi)$, $\lambda_y(r, \psi)$, and $\lambda_z(r, \psi)$ used by CAMRAD:

$$\begin{bmatrix} \lambda_x \\ \lambda_y \\ \lambda_z \end{bmatrix} = \begin{bmatrix} -u\cos\psi \\ u\sin\psi \\ w \end{bmatrix}$$

APPENDIX B
Velocity Components Induced by Wake Vortex Elements

Vortex Line

$$u_I(r, p, h, \Gamma) = \frac{\Gamma}{2\pi}\left[\frac{h}{(p + r)^2 + h^2} - \frac{h}{(p - r)^2 + h^2}\right]$$

$$w_I(r, p, h, \Gamma) = \frac{\Gamma}{2\pi}\left[\frac{p + r}{(p + r)^2 + h^2} + \frac{p - r}{(p - r)^2 + h^2}\right]$$

$$u_F(r, p, h, \Gamma) = -\frac{\Gamma}{4\pi}\,\ell n\left(\frac{h^2 + (p + r)^2}{h^2 + (p - r)^2}\right)$$

$$w_F(r, p, h, \Gamma) = \frac{\Gamma}{2\pi}\left[\pi - \arctan\left(\frac{h}{p - r}\right) - \arctan\left(\frac{h}{p + r}\right)\right] \qquad \text{for } p < r$$

$$= \frac{\Gamma}{2\pi}\left[\frac{\pi}{2} - \arctan\left(\frac{h}{p + r}\right)\right] \qquad \text{for } p = r$$

$$= -\frac{\Gamma}{2\pi}\left[\arctan\left(\frac{h}{p - r}\right) + \arctan\left(\frac{h}{p + r}\right)\right] \qquad \text{for } p > r$$

Vortex Ring

$$u_I(r, p, h, \Gamma) = -\frac{\Gamma}{4\pi}\frac{h}{2r}\sqrt{\frac{k^2}{pr}}\left[\frac{E(2 - k^2)}{(1 - k^2)} - 2K\right]$$

$$w_I(r, p, h, \Gamma) = \frac{\Gamma}{4\pi}\sqrt{\frac{k^2}{pr}}\left[K - \frac{E\{1 - \frac{1}{2}k^2(1 + p/r)\}}{(1 - k^2)}\right]$$

$$u_F(r, p, h, \Gamma) = -\frac{\Gamma}{2\pi k}\sqrt{\frac{p}{r}}\left[K(2 - k^2) - 2E\right]$$

$$w_F(r, p, h, \Gamma) = \frac{\Gamma}{2\pi}\int_0^{\pi}\left(\frac{p(p - r\cos\phi)}{r^2 + p^2 - 2pr\cos\phi}\left[1 - \frac{h}{r^2 + p^2 + h^2 - 2pr\cos\phi}\right]\right)d\phi$$

where the latter is integrated numerically, and

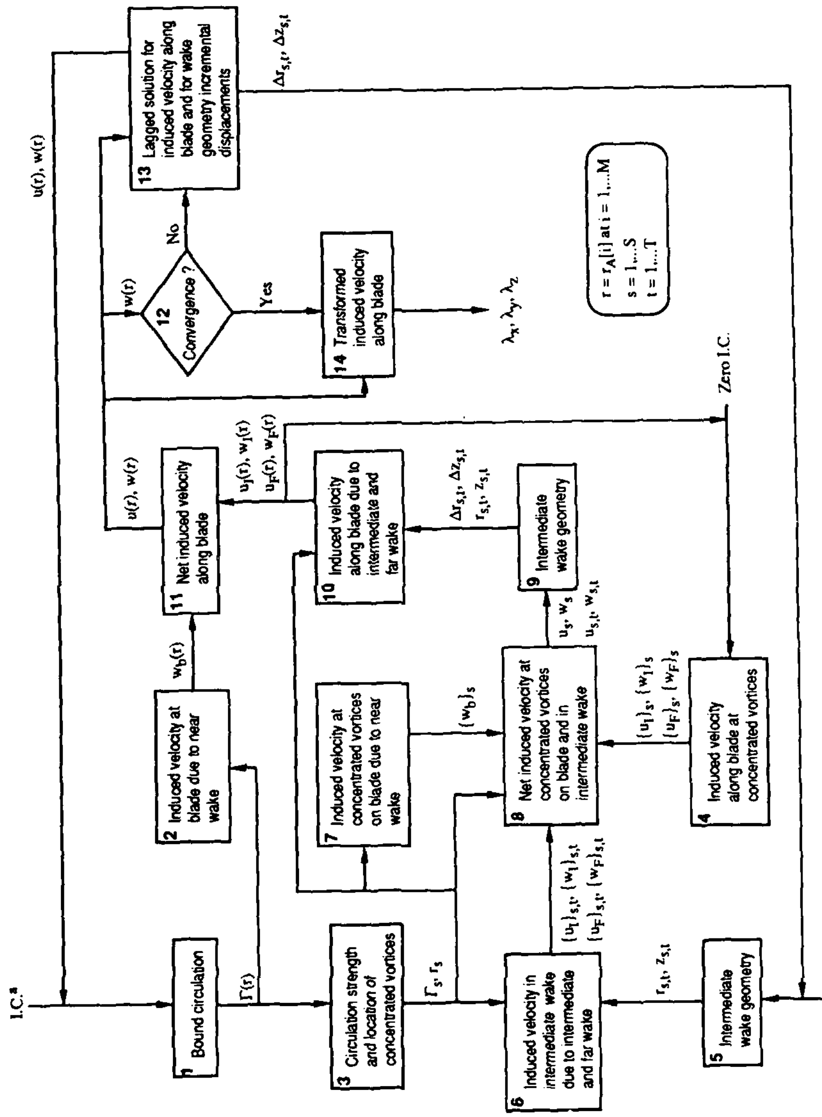
$$k^2 = \frac{4pr}{(p + r)^2 + h^2}$$

$$E = 1 + \tfrac{1}{2}(F - \tfrac{1}{2})(1 - k^2) + \tfrac{3}{16}(F - \tfrac{13}{12})(1 - k^2)^2$$

$$K = F + \tfrac{1}{4}(F - 1)(1 - k^2) + \tfrac{9}{64}(F - \tfrac{7}{6})(1 - k^2)^2$$

$$F = \ell n\left(\frac{4}{\sqrt{1 - k^2}}\right)$$

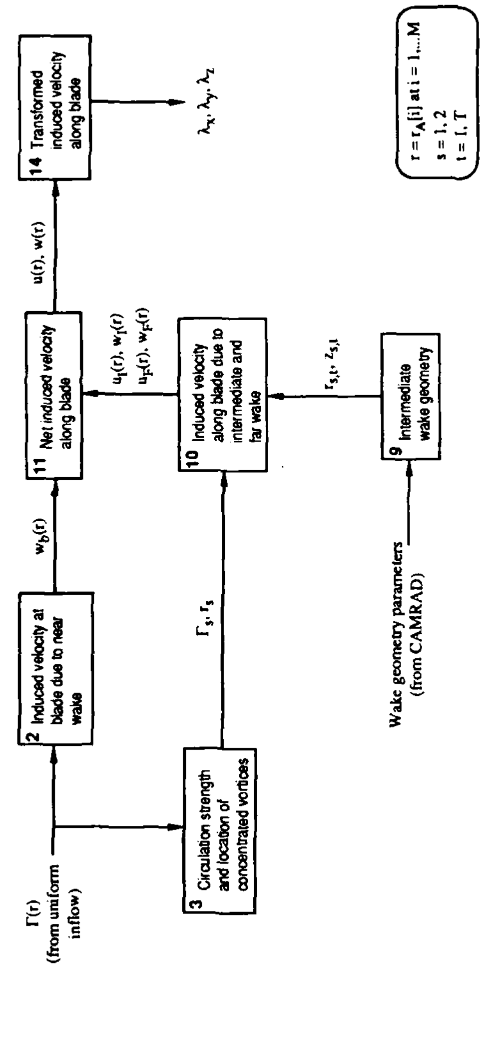
APPENDIX C
Block Diagram for Free Wake Method



^a Initial condition using $\lambda_z(r)$ given by uniform inflow method from CAMRAD

Note: Numbers in upper left corner of boxes refer to step numbers in Appendix A

APPENDIX D
Block Diagram for Prescribed Wake Method



Note: Numbers in upper left corner of boxes refer to step numbers in Appendix A

APPENDIX E
Modified CAMRAD Subprograms

```
      SUBROUTINE GEOMR1(LEVEL)
...
...
      COMMON /KTIP/KT                                                    MOD
...
...
C
C   CALCULATE WAKE GEOMETRY DISTORTION
C
...
...
C
C   FOR KOCUREK AND TANGLER AND LANDGREBE MODELS, FWGT(1) AND FWGT(2)   MOD
C   ARE USED AS FACTORS FOR KT(1) AND KT(2)                              MOD
C
C   KOCUREK AND TANGLER
      FB=.000729*TW
      FC=2.3-.206*TW
      FM=1.-.25*EXP(.04*TW)
      FN=.5-.0172*TW
      KT(1)=(FB+FC*(ABS(CTG)/FLOAT(NBLADE)**FN)**FM)*FWGT(1)             MOD
      KT(2)=SQRT(ABS(CTG-FLOAT(NBLADE)**FN*(ABS(-FB/FC))**(1./FM)))
     1*FWGT(2)                                                           MOD
      KT(3)=4.*CTH
      KT(4)=.78
      GO TO 17
C   LANDGREBE
   16 KT(1)=.25*(CTOS+.001*TW)*FWGT(1)                                   MOD
      KT(2)=(1.+.01*TW)*CTH*FWGT(2)                                      MOD
      KT(3)=.145+27.*CTG
      KT(4)=.78
...
...
      SUBROUTINE INPTW1
      COMMON /W1DATA/FACTWN,OPVXVY,KNW,KRW,KFW,KDW,RRU,FRU,PRU,FNW,DVS,D
     1LS,CORE(5),OPCORE(2),WKMODL(13),OPNWS(2),LHW,OPHW,OPRTS,VELB,DPHIB
     2,DBV,QDEBUG,MRG,NG(30),MRL,NL(30),OPWKBP(3),KRWG,OPRWG,FWGT(2),FWG
     3SI(2),FWGSO(2),KWGT(4),KWGSI(4),KWGSO(4)
      INTEGER OPVXVY,OPCORE,WKMODL,OPNWS,OPHW,OPRTS,OPWKBP,OPRWG
     1    ,NIVL,NIBV,WFMODL,OPMODL,ITERV                                 MOD
      REAL KWGT,KWGSI,KWGSO
     1    ,RIBB(8),FGAMMA                                                MOD

      COMMON /G1DATA/KFWG,OPFWG,ITERWG,FACTWG,WGMODL(2),RTWG(2),COREWG(4
     1),MRVBWG,LDMWG,NDMWG(36),IPWGDB(2),QWGDB,DQWG(2)
      INTEGER OPFWG,WGMODL
      COMMON /TMDATA/TMXX(182)
      INTEGER DEBUG
      EQUIVALENCE (TMXX(41),DEBUG)
      COMMON /UNITNO/NFDAT,NFAF1,NFAF2,NFRS,NFEIG,NFSCR,NUDB,NUOUT,NUPP,
     1NULIN,NUIN
      COMMON /RING/ NIBV,RIBB,NIVL,FACTIV,EPIVEL,WFMODL,OPMODL,FGAMMA,   MOD
     1        ITERV                                                      MOD
```

```
C
C   READ WAKE NAMELIST
C
      NAMELIST /NLWAKE/FACTWN,OPVXVY,KNW,KRW,KFW,KDW,RRU,FRU,PRU,FNW,DVS
     1,DLS,CORE,OPCORE,WFMODL,OPNWS,LHW,OPHW,OPRTS,VELB,DPHIB,DBV,QDEBUG
     2,MRG,NG,MRL,NL,OPWKBP,KRWG,OPRWG,FWGT,FWGSI,FWGSO,KWGT,KWGSI,KWGSO
     3,KFWG,OPFWG,ITERWG,FACTWG,WGMODL,RTWG,COREWG,MRVBWG,LDMWG,NDMWG,IP
     4WGDB,QWGDB,DQWG
     5 ,NIVL,RIBB,NIBV,FACTIV,EPIVEL,WFMODL,OPMODL,FGAMMA,ITERV         MOD
C                                                                       MOD
C -------------- DEFAULT VALUES FOR VORTEX LINE/RING -------------------MOD
C                                                                       MOD
      NIBV=2                                                            MOD
      DO I=1,8                                                          MOD
         RIBB(I)=0.0                                                    MOD
      END DO                                                            MOD
      NIVL=4                                                            MOD
      FACTIV=0.1                                                        MOD
      EPIVEL=0.05                                                       MOD
      WFMODL=2                                                          MOD
      OPMODL=0                                                          MOD
      FGAMMA=0.6                                                        MOD
      ITERV=200                                                         MOD
C -------------------------- END ---------------------------------------MOD
  999 FORMAT (1X,33HREADING NAMELIST NLWAKE (ROTOR 1))
      WRITE (NUOUT,999)
      READ (NUIN,NLWAKE)
      IF (DEBUG .GE. 2) WRITE (NUDB,NLWAKE)
      RETURN
      END


      SUBROUTINE PRNTW1
...
...
      COMMON /R1DATA/R1XX(932)                                          MOD
      EQUIVALENCE (R1XX(81),RROOT)                                      MOD
      EQUIVALENCE (TMXX(77),MPSI),(TMXX(157),LEVEL)
      COMMON /UNITNO/NFDAT,NFAF1,NFAF2,NFRS,NFEIG,NFSCR,NUDB,NUOUT,NUPP,
     1NULIN,NUIN
      REAL RIBB(8),FGAMMA                                               MOD
      INTEGER NIVL,WFMODL,OPMODL,NIBV,ITERV                             MOD
      COMMON /RING/ NIBV,RIBB,NIVL,FACTIV,EPIVEL,WFMODL,OPMODL,FGAMMA,  MOD
     1       ITERV                                                      MOD
C
C   PRINT WAKE INPUT DATA
C
...
...
C
C ------------------- VORTEX RING/LINE ---------- ---------------------
C
991   FORMAT(//1X,'VORTEX LINE AND VORTEX RING MODELS (PRESCRIBED AND FR
     1EE)'/5X,'NUMBER OF INTERMEDIATE VORTEX LEVELS,  NIVL =',I3/5X,'FAR
     2 WAKE MODEL (0 TO OMIT, 1 FOR CONCENTRATED, 2 FOR SHEET),  WFMODL
     3=',I3//5X,'FOR FREE WAKE ONLY'//5X,'FACTOR INTRODUCING LAG IN INDU
     4CED VELOCITY,  FACTIV =',F10.4/5X,'TOLERANCE FOR INDUCED VELOCITY,
     5 EPIVEL =',F10.4/5X,'ROLLED-UP VORTEX WEIGHTING FACTOR (EXCLUDING
     6TIP),  FGAMMA =',F9.4/5X,'MAXIUM NUMBER OF INDUCED VELOCITY ITERAT
     7IONS,  ITERV =',I4/5X,'NUMBER OF ROLLED-UP VORTICIES,  NIBV =',I3)
```

```
986   FORMAT(/5X,'INBOARD EDGE OF ROLLED-UP VORTICIES, EXCLUDING ROOT AN
     1D TIP (NIBV-2 VALUES),'//15X,'RIBB =',8(F9.4))
C
C ---------------------------- END -----------------------------------
C
...
...
  999 FORMAT (//1X,23HNONUNIFORM INFLOW MODEL/                          MOD
     *5X,'VORTEX LINE MODEL IF 1, VORTEX RING MODEL IF 2,  OPMODL =',I3/MOD
     *                                      5X,27HEXTENT OF NEAR WAKE,MOD
     1  KNW =,I5/5X,33HEXTENT OF ROLLING UP WAKE,  KRW =,I5/5X,26HEXTENT
     2 OF FAR WAKE,  KFW =,I5/5X,30HEXTENT OF DISTANT WAKE,  KDW =,I5/5X
     3,37HROLLUP INITIAL RADIAL STATION,  RRU =,F10.4/5X,42HROLLUP INITI
     4AL TIP VORTEX FRACTION,  FRU =,F10.4/5X,27HROLLUP EXTENT (DEG),  P
     4RU =,F10.2/5X,37HNEAR WAKE TIP VORTEX FRACTION,  FNW =,F10.4/5X,50
     5HNUMBER OF SPIRALS IN AXISYMMETRIC FAR WAKE,  LHW =,I5/5X,40HAXISY
     6MMETRIC WAKE GEOMETRY IF 0,  OPHW =,I3)
...
...
      WRITE (NUOUT,990) KRWG,OPRWG,(FWGT(I),FWGSI(I),FWGSO(I), I=1,2),(K
     1WGT(I),KWGSI(I),KWGSO(I), I=1,4)
      WRITE (NUOUT,991) NIVL,WFMODL,FACTIV,EPIVEL,FGAMMA,ITERV,NIBV     MOD
      IF (NIBV .GT. 2) THEN                                             MOD
         IF (RIBB(1) .LT. RROOT) THEN                                   MOD
            DRI=(0.9-RROOT)/FLOAT(NIBV-1)                               MOD
            DO I=1,NIBV-2                                               MOD
               RIBB(I)=RROOT+I*DRI                                      MOD
            END DO                                                      MOD
         END IF                                                         MOD
         WRITE(NUOUT,986) (RIBB(I),I=1,NIBV-2)                          MOD
      END IF                                                            MOD
      IF (LEVEL .LE. 1) GO TO 1
...
...
      SUBROUTINE RAMF(LEVEL1,LEVEL2,OPLMDA)
...
...
      COMMON /RING/RIXX(16)                                             MOD
      INTEGER OPRTR2,DEBUG,MHARM(2),MHARMF(2)
     1,OPMODL                                                           MOD
      EQUIVALENCE (TMXX(77),MPSI),(TMXX(179),MHARM(1)),            (TM
     1XX(91),ITERM),(TMXX(92),EPMOTN),(TMXX(93),ITERC),(TMXX(94),EPCIRC)
     2,(TMXX(49),DEBUG),(TMXX(90),MREV),(TMXX(89),MPSIR),(TRIMXX(11),OPR
     3TR2),(RTR1XX(4),CMEAN1),(RTR1XX(6),NBM1),(RTR1XX(7),NTM1),(RTR1XX(
     48),NGM1),(RTR2XX(4),CMEAN2),(RTR2XX(6),NBM2),(RTR2XX(7),NTM2),(RTR
     52XX(8),NGM2),(BODYXX(254),NAM),(ENGNXX(11),NDM),(TMXX(181),MHARMF(
     61)),(R1XX(24),SIGMA1),(R2XX(24),SIGMA2)
     7 ,(RIXX(14),OPMODL)                                               MOD
      COMMON /UNITNO/NFDAT,NFAF1,NFAF2,NFRS,NFEIG,NFSCR,NUDB,NUOUT,NUPP,
     1NULIN,NUIN
C
C   CALCULATE ROTOR/AIRFRAME PERIODIC MOTION AND FORCES
C
...
...
C   CALCULATE INDUCED VELOCITY
C
      CALL WAKEU1
```

```
C ---------------- VORTEX RING/LINE -------------------                MOD
                                                                       MOD
      IF(OPMODL.GT.0.AND.LEVEL1.NE.0) THEN                             MOD
        CALL WAKER1(LEVEL1)                                            MOD
        GOTO 14                                                        MOD
      ENDIF                                                            MOD
C ---------------------- END -------------------------                 MOD
      CALL WAKEN1(LEVEL1)
...
...
C   END MOTION ITERATION
C   TEST CIRCULATION CONVERGENCE
      OUT=0
      IF (LEVEL1 .EQ. 0) GO TO 53
      IF ((LEVEL1 .EQ. 2) .AND. (OPMODL .GT. 0)) GO TO 205             MOD
      G1MS=0.
...
...


      SUBROUTINE TRIM
      COMMON /TMDATA/TMXX(182)
      COMMON /TRIMCM/TRIMXX(1604)
      COMMON /CASECM/CASEXX(9)
      COMMON /RING/RIXX(16)                                            MOD
      INTEGER RESTRT,RSWRT,OPRTR2
     1     ,OPMODL                                                     MOD
      EQUIVALENCE (TMXX(157),LEVEL1),(TMXX(158),LEVEL2),(TMXX(159),ITERU
     1),(TMXX(160),ITERR),(TMXX(161),ITERF),(TMXX(162),NPRNTT),(TMXX(163
     2),NPRNTP),(TMXX(164),NPRNTL),(CASEXX(1),RESTRT),(CASEXX(5),RSWRT),
     3(TRIMXX(11),OPRTR2)
     4 ,(RIXX(14),OPMODL)                                              MOD
      COMMON /UNITNO/NFDAT,NFAF1,NFAF2,NFRS,NFEIG,NFSCR,NUDB,NUOUT,NUPP,
     1NULIN,NUIN
C
C   TRIM
C
...
...
C   NONUNIFORM INFLOW AND PRESCRIBED WAKE
    2 IF (LEVEL .EQ. 1) ITERR=MAX0(ITERR,1)
      IF (ITERR .LE. 0) GO TO 3
      DO 20 IT=1,ITERR
      IF (LEVEL1 .EQ. 0) GO TO 22
      LEV1=1
C -----------------VORTEX LINE/RING ------------------------------MOD
      IF(OPMODL.GT.0) THEN                                             MOD
          CALL GEOMR1(LEV1)                                            MOD
          GOTO 22                                                      MOD
      END IF                                                           MOD
C ------------------------ END -----------------------------------MOD
C
      CALL WAKEC1(LEV1)
...
...
```

```
C   NONUNIFORM INFLOW AND FREE WAKE
    3 ITERF=MAX0(ITERF,1)
      DO 30 IT=1,ITERF
      IF (LEVEL1 .EQ. 0) GO TO 32
      LEV1=LEVEL1
C
      IF(OPMODL.GT.0) GO TO 32                                        MOD
C
      CALL WAKEC1(LEV1)
...
...
      SUBROUTINE TIMER(N,I,T)
      COMMON /TIMECM/TSTART(14),TSUM(14),NCALLS(14),IDBSAV(23),ICNT
      COMMON /TMDATA/TMXX(182)
      EQUIVALENCE (TMXX(64),DEBUG),(TMXX(41),IDB(1)),(TMXX(40),ITDB)
      INTEGER DEBUG,IDB(23)
      INTEGER*4 ITIME,HANDLE_ADR,CODE                                 MOD
      COMMON /UNITNO/NFDAT,NFAF1,NFAF2,NFRS,NFEIG,NFSCR,NUDB,NUOUT,NUPP,
     1NULIN,NUIN
C
C   PROGRAM TIMER
C
      REAL TFRACT(14),TCALL(14)
      INTEGER ID(2,14)
      DATA MT/14/
      DATA ID/4HCASE,4H    ,4HTRIM,4H    ,4HFLUT,4H    ,4HSTAB,4H    ,4H
     1TRAN,4H    ,4HSTAB,4HL   ,4HFLUT,4HL   ,4HWAKE,4HC   ,4HGEOM,4HR
     2 ,4HRAMF,4H    ,4HMODE,4H    ,4HMOTN,4HR   ,4HPERF,4H    ,4HLOAD,4
     3H    /
  999 FORMAT (1H1,17HCOMPUTATION TIMES//50X,8HCPU TIME,4X,7HPERCENT,8X,6
     1HNUMBER,3X,9HTIME/CALL/52X,5H(SEC),19X,8HOF CALLS,4X,5H(SEC)/)
  998 FORMAT (1X,6HTIME =,F12.3,4H SEC)
  997 FORMAT (1X,6HTIME =,F12.3,4H SEC,5X,7H(START ,2A4,1H))
  996 FORMAT (1X,6HTIME =,F12.3,4H SEC,5X,5H(END ,2A4,1H),5X,12H(CALL NU
     1MBER,I3,18H, TIME INCREMENT =,F12.3,5H SEC))
  901 FORMAT (10X,4HCASE,31X,2F12.3,I12,F12.3)
  902 FORMAT (10X,11HTRIM (TRIM),24X,2F12.3,I12,F12.3)
  903 FORMAT (10X,14HFLUTTER (FLUT),21X,2F12.3,I12,F12.3)
  904 FORMAT (10X,22HFLIGHT DYNAMICS (STAB),13X,2F12.3,I12,F12.3)
  905 FORMAT (10X,16HTRANSIENT (TRAN),19X,2F12.3,I12,F12.3)
  906 FORMAT (10X,23HLINEAR ANALYSIS (STABL),12X,2F12.3,I12,F12.3)
  907 FORMAT (10X,23HLINEAR ANALYSIS (FLUTL),12X,2F12.3,I12,F12.3)
  908 FORMAT (10X,25HNONUNIFORM INFLOW (WAKEC),10X,2F12.3,I12,F12.3)
  909 FORMAT (10X,21HWAKE GEOMETRY (GEOMR),14X,2F12.3,I12,F12.3)
  910 FORMAT (10X,25HVIBRATORY SOLUTION (RAMF),10X,2F12.3,I12,F12.3)
  911 FORMAT (10X,18HROTOR MODES (MODE),17X,2F12.3,I12,F12.3)
  912 FORMAT (10X,23HROTOR EQUATIONS (MOTNR),12X,2F12.3,I12,F12.3)
  913 FORMAT (10X,18HPERFORMANCE (PERF),17X,2F12.3,I12,F12.3)
  914 FORMAT (10X,12HLOADS (LOAD),23X,2F12.3,I12,F12.3)
      CODE=2
      IF (N .EQ. 0) GO TO 10
      IF (N .EQ. 1) GO TO 11
      IF (N .EQ. 2) GO TO 12
      IF (N .EQ. 3) GO TO 13
C   RETURN PRESENT TIME
      IERROR=LIB$STAT_TIMER (CODE,ITIME,HANDLE_ADR)                    VAX
      T=.01*FLOAT(ITIME)                                              VAX
      IF (DEBUG .GE. 1) WRITE (NUOUT,998) T
      RETURN
C   INITIALIZE
   10 CONTINUE
      IERROR=LIB$INIT_TIMER (HANDLE_ADR)                              VAX
```

```
      DO 100 JT=1,MT
      TSUM(JT)=0.
      NCALLS(JT)=0
  100 TSTART(JT)=0.
      ICNT=0
      RETURN
C   START TIMER
   11 CONTINUE
      IERROR=LIB$STAT_TIMER(CODE,ITIME,HANDLE_ADR)                      VAX
      T=.01*FLOAT(ITIME)                                                VAX
      TSTART(I)=T
      IF (DEBUG .GE. 1) WRITE (NUOUT,997) T,ID(1,I),ID(2,I)
      IF (I .LE. 1) GO TO 113
      IF (ICNT .EQ. 1) GO TO 111
      DO 112 II=1,23
      IDBSAV(II)=IDB(II)
  112 IDB(II)=0
      ICNT=1
  111 IF (ITIME .LT. ITDB*1000) GO TO 113
      DO 114 II=1,23
  114 IDB(II)=IDBSAV(II)
  113 CONTINUE
      RETURN
C   STOP TIMER
   12 CONTINUE
      IERROR=LIB$STAT_TIMER(CODE,ITIME,HANDLE_ADR)                      VAX
      T=.01*FLOAT(ITIME)                                                VAX
      DT=T-TSTART(I)
      TSUM(I)=TSUM(I)+DT
      NCALLS(I)=NCALLS(I)+1
      IF (DEBUG .GE. 1) WRITE (NUOUT,996) T,ID(1,I),ID(2,I),NCALLS(I),DT
      RETURN
C   PRINT TIMES
   13 CONTINUE
      TCASE=TSUM(1)
      IF (TCASE .NE. 0.) TCASE=100./TCASE
      DO 130 JT=1,MT
      TFRACT(JT)=TSUM(JT)*TCASE
      TCALL(JT)=0.
      IF (NCALLS(JT) .NE. 0) TCALL(JT)=TSUM(JT)/FLOAT(NCALLS(JT))
  130 CONTINUE
      WRITE (NUOUT,999)
      WRITE (NUOUT,901) TSUM(1),TFRACT(1),NCALLS(1),TCALL(1)
      WRITE (NUOUT,902) TSUM(2),TFRACT(2),NCALLS(2),TCALL(2)
      WRITE (NUOUT,903) TSUM(3),TFRACT(3),NCALLS(3),TCALL(3)
      WRITE (NUOUT,904) TSUM(4),TFRACT(4),NCALLS(4),TCALL(4)
      WRITE (NUOUT,905) TSUM(5),TFRACT(5),NCALLS(5),TCALL(5)
      WRITE (NUOUT,906) TSUM(6),TFRACT(6),NCALLS(6),TCALL(6)
      WRITE (NUOUT,907) TSUM(7),TFRACT(7),NCALLS(7),TCALL(7)
      WRITF (NUOUT,908) TSUM(8),TFRACT(8),NCALLS(8),TCALL(8)
      WRITE (NUOUT,909) TSUM(9),TFRACT(9),NCALLS(9),TCALL(9)
      WRITE (NUOUT,910) TSUM(10),TFRACT(10),NCALLS(10),TCALL(10)
      WRITE (NUOUT,911) TSUM(11),TFRACT(11),NCALLS(11),TCALL(11)
      WRITE (NUOUT,912) TSUM(12),TFRACT(12),NCALLS(12),TCALL(12)
      WRITE (NUOUT,913) TSUM(13),TFRACT(13),NCALLS(13),TCALL(13)
      WRITE (NUOUT,914) TSUM(14),TFRACT(14),NCALLS(14),TCALL(14)
      RETURN
      END
```

APPENDIX F
Added CAMRAD Subprograms

```
      SUBROUTINE WAKER1(LEVEL)
C-----------------------------------------------------------------------
C     DETERMINE THE INDUCED VELOCITY AT THE ROTOR USING A VORTEX
C     LINE OR RING MODEL
C
C     THE WAKE MAY BE EITHER PRESCRIBED OR FREE
C
C     THE FAR WAKE MAY BE EITHER NEGLECTED OR REPRESENTED AS A
C     DISTRIBUTED OR CONCENTRATED VORTEX

      INTEGER DEBUGG,DEBUGV,I,IR,IT,J,JPSI,JR,JT,LEVEL,M,MPSI,MRA,N,
     1     NBLADE,NIBV,NTM,NTM1,OPCOMP,OPMODL,S,SMAX,T,NIVL,WFMODL,
     2     MS(0:10),ICOUNT,ITERV
      REAL ALPHA,AREA,BETAC,BETAS,CL,COREB,CVERT,D5,DA,DBV,DELW,DGAM,
     1     DGAMR,DU,DW,E,EPIVEL,EPR,ERR,FACTIV,FACTOR,FOLD,GAMR,H,
     2     LAMBDA,MACH,MTIP,PI,Q1,RMN,RROOT,T75,URES,WMAX,ZST,ANGL(30),
     3     DR(10,36),DZ(10,36),GAMA(30),GS(10),R(10,36),DROLD(10,36),
     4     RS(10),RUB(0:10),U(30),UIF(10,36),UNW(10,36),UOLD(30),US(10),
     5     W(30),WB(30),WIF(10,36),WIFR(30),WNW(10,36),WOLD(30),WRU(10),
     6     WS(10),WSELF(10),Z(10,36),DZOLD(10,36),RIBB(8),FGAMMA

      CHARACTER CHAR*2
C
C   ------------    CAMRAD COMMON BLOCK    --------------
      COMMON /R1DATA/R1XX(932)
      COMMON /RTR1CM/RTR1XX(1070)
      COMMON /CONTCM/CONTXX(32)
      COMMON /WKV1CM/WKV1XX(8165)
      COMMON /TMDATA/TMXX(182)
      COMMON /TRIMCM/TRIMXX(1604)
      COMMON /W1DATA/W1XX(126)
      COMMON /QR1CM/QR1XX(1139)
      COMMON /MD1CM/MD1XX(6773)
      COMMON /AEMNCM/AEMNXX(78)

      COMMON /RING/ NIBV,RIBB,NIVL,FACTIV,EPIVEL,WFMODL,OPMODL,FGAMMA,
     1      ITERV

      REAL RA(30),TWIST(30),CHORD(30),VIND(3,30,36),GAMOLD(30,36),
     1   SINPSI(36),COSPSI(36),THETZL(36),DRA(30),RAE(31),GAM(30,36),
     2   ZETA(5,30),P1(5),CRCOLD(36),CRC(36),CORE(2)
C
      EQUIVALENCE (R1XX(150),MRA),(RTR1XX(20),RA(1)),(CONTXX(1),T75),
     1    (R1XX(272),TWIST(1)),(R1XX(302),THETZL(1)),(W1XX(1),FACTOR),
     2    (R1XX(182),CHORD(1)),(QR1XX(24),GAM(1,1)),(R1XX(81),RROOT),
     3    (WKV1XX(1120),VIND(1,1,1)),(R1XX(26),NBLADE),(TMXX(77),MPSI),
     4    (TRIMXX(57),SINPSI(1)),(R1XX(80),OPCOMP),(RTR1XX(7),NTM),
     5    (TRIMXX(21),COSPSI(1)),(W1XX(13),CORE(1)),(W1XX(40),DBV),
     6    (RTR1XX(2),MTIP),(WKV1XX(4360),LAMBDA),(QR1XX(1104),CRC(1)),
     7    (QR1XX(22),BETAC),(QR1XX(23),BETAS),(RTR1XX(50),DRA(1)),
     8    (R1XX(151),RAE(1)),(WKV1XX(4),GAMOLD(1,1)),(TMXX(53),DEBUGV),
     9    (TMXX(63),DEBUGG),(MD1XX(6148),ZETA(1,1)),(AEMNXX(31),P1(1)),
     A    (WKV1XX(1084),CRCOLD(1))
C
      COMMON /UNITNO/NFDAT,NFAF1,NFAF2,NFRS,NFEIG,NFSCR,NUDB,NUOUT,NUPP,
     1NULIN,NUIN
C
C -----------------    END CAMRAD COMMON BLOCK    ----------------
```

```
C
      COMMON /HELICOM/Q1,W,U,GAMA,RS,GS,WS,US,DZ,R,DR,Z,WIFR,SMAX

899   FORMAT(/1X,'RING/LINE LEVEL    ',10(I9))
900   FORMAT(/1X,'VORTEX NO.',I4,'    R=',10(F9.5))
901   FORMAT(18X,'Z=',10(F9.5))
902   FORMAT(/1X,'STRENGTH OF ROLLED UP VORTEX',F10.6)
903   FORMAT(5X,10(F9.5))
904   FORMAT(1X,A2,2X,10(F9.5))

C
C  INITIALIZE VARIABLES
C
      DATA PI/3.14159265/
      IF (LEVEL .EQ. 1) THEN
        SMAX=2
       ELSE
        SMAX=NIBV
      END IF
      MS(0)=MRA+1
      RUB(0)=RAE(MRA+1)
      MS(SMAX)=1
      RUB(SMAX)=RROOT
      IF (SMAX .LE. 2) GO TO 20
C TEST DATA FOR FATAL ERRORS
      DO I=1,NIBV-2
         IF (I .EQ. 1) THEN
            IF (RIBB(I) .LT. RROOT) GO TO 10
           ELSE
            IF (RIBB(I) .LT. RIBB(I-1)) THEN
               WRITE(NUDB,*) 'ERROR IN DATA :LOCATION OF INBOARD VORTEX
     1BOUNDARIES'
               GO TO 10
            END IF
         END IF
      END DO
      DO I=1,NIBV-2
         S=SMAX-I
         RUB(S)=RIBB(I)
      END DO
      GO TO 20
 10   DRI=(0.9-RROOT)/FLOAT(NIBV-1)
      DO I=0,NIBV-2
         S=SMAX-I
         RUB(S-1)=RUB(S)+DRI
      END DO
 20   NTM1=MAX0(1,NTM)
      ICOUNT=1
      CVERT=180./PI
      Q1=2.0*PI/FLOAT(NBLADE)
      IT=0
C
C GEOMETRIC PITCH AND INDUCED VELOCITY FROM CAMRAD
C (FREE WAKE ONLY)
C
      IF (LEVEL .EQ. 2) THEN
         DO IR=1,MRA
            ANGL(IR)=T75+(TWIST(IR)+THETZL(IR))/CVERT
            W(IR)=-VIND(3,IR,1)
            DO JT=1,NTM1
               ANGL(IR)=ANGL(IR)+ZETA(JT,IR)*P1(JT)
            END DO
```

```
            END DO
         END IF
C
C POSITIONS OF ROLL-UP BOUNDARIES
C
         IF (SMAX .GT. 2) THEN
            DO I=2,SMAX-1
               S=I
               DO JR=1,MRA
                  J=JR
                  IF (RAE(J) .GE. (RUB(S)-1.E-4)) GO TO 101
C
C RUB(S) IS INBOARD LIMIT OF THE VORTEX ROLL-UP BOUNDARY
C
               END DO
101            MS(S)=J
            END DO
         END IF
         MS(0)=MRA+1
         RUB(0)=RAE(MRA+1)
         MS(SMAX)=1
         RUB(SMAX)=RROOT
C
C   BEGINNING OF LOOP FOR NEXT ITERATION
C
C   COMPUTE BLADE BOUND CIRCULATION
C
70       IF(LEVEL .EQ. 1) THEN
C
C   FROM CAMRAD
C
            FOLD=1.0-FACTOR
            DO JPSI=1,MPSI
               CRCOLD(JPSI)=FOLD*CRCOLD(JPSI)+FACTOR*CRC(JPSI)
               DO IR=1,MRA
                  GAMOLD(IR,JPSI)=FOLD*GAMOLD(IR,JPSI)+FACTOR
     1            *GAM(IR,JPSI)
                  GAMA(IR)=GAMOLD(IR,JPSI)
               END DO
            END DO
           ELSE
C
C  FROM INDUCED VELOCITY
C
            DO 80 JR=1,MRA
C
C    DETERMINE ALPHA,URES,MACH,COSL

               ALPHA=(ANGL(JR)-W(JR)/RA(JR))*CVERT
               URES=W(JR)*W(JR)+RA(JR)*RA(JR)
               IF(URES.NE.0.0) URES=SQRT(ABS(URES))
               MACH=URES*MTIP
               IF(OPCOMP.EQ.0) MACH=0.0

C    LIFT COEFFICIENT

               CALL AEROT1(ALPHA,MACH,RA(JR),1,CL,CD,CM)

C    CIRCULATION

               GAMA(JR)=0.5*CL*URES*CHORD(JR)
C
```

```
   80    CONTINUE
      END IF
C
C  LOOP TO FIND STATION OF MAX. CIRCULATION
C
      DO 90 JR=MRA,2,-1
         J=JR
         IF(GAMA(J) .GT. GAMA(J-1)) GO TO 100
   90 CONTINUE
  100 MS(1)=J     !   MS(1) IS LOCATION OF MAX. CIRCULATION ON BLADE
      RUB(1)=RAE(J)
C
C     COMPUTE INDUCED VELOCITY AT BLADE DUE TO NEAR TRAILING WAKE
C     {DUE TO SHEET}
C
  105 DO 111 IR=1,MRA
         WB(IR)=0.0
         DO 110 JR=1,MRA+1
            IF (JR .EQ. 1) THEN
               DELW=-1/(4.*PI)*(GAMA(JR))*
     1         (1.0/(RAE(JR)-RA(IR))+1.0/(RAE(JR)+RA(IR)))
              ELSE IF (JR .EQ. (MRA+1)) THEN
               DELW=1/(4.*PI)*(GAMA(JR-1))*
     1         (1.0/(RAE(JR)-RA(IR))+1.0/(RAE(JR)+RA(IR)))
              ELSE
               DELW=-1/(4.*PI)*(GAMA(JR)-GAMA(JR-1))*
     1         (1.0/(RAE(JR)-RA(IR))+1.0/(RAE(JR)+RA(IR)))
            END IF
            WB(IR)=WB(IR)+DELW
  110    CONTINUE
  111 CONTINUE
C
C  PRESCRIBED WAKE GEOMETRY
C
      IF(LEVEL .EQ. 1) THEN
        CALL PRESWG(MS(1))
        GO TO 306
      END IF
C
C     FIND CENTROID OF VORTEX, RS(S)
C
      DO S=1,SMAX
         GS(S)=0.0
         GAMR=0.0
         DO 120 JR=MS(S)+1,MS(S-1)
            IF (JR .EQ. 2) THEN
               DGAM=GAMA(JR)
              ELSE IF (JR .EQ. (MRA+1)) THEN
               DGAM=-GAMA(JR-1)
              ELSE
               DGAM=GAMA(JR)-GAMA(JR-1)
            END IF
            GS(S)=GS(S)-DGAM
C
C     GS(S) IS THE CIRCULATION OF THE VORTEX, S
C
            DGAMR=DGAM*RAE(JR)
            GAMR=GAMR+DGAMR
  120    CONTINUE
         IF (ABS(GS(S)) .LT. 1.E-10) THEN
            RS(S)=(RUB(S)+RUB(S-1))/2.0
           ELSE
```

```
            RS(S)=ABS(GAMR/GS(S))     !  LOCATION OF VORTEX, S
            IF (S .NE. 1) GS(S)=GS(S)*FGAMMA
         END IF
      END DO
C
C     FIND VELOCITIES AT RS(S), WS(S), AND US(S)
C
      DO I=1,SMAX
         S=I
         DO J=MS(S),MS(S-1)
            JR=J
            IF (RS(S) .LT. RAE(JR)) GO TO 160
         END DO
C
C  INDUCED VELOCITY
C
160      CALL IVTERP(S,JR)
C
         IF (IT .EQ. 0) THEN
            WS(S)=0.0
            US(S)=0.0
         END IF
      END DO
      IF (IT .EQ. 2) THEN
         DO S=1,SMAX
            DO T=1,TMAX
               IF (T .EQ. 1) THEN
                  Z(S,T)=DZ(S,T)
                  R(S,T)=RS(S)+DR(S,T)
                 ELSE
                  Z(S,T)=Z(S,T-1)+DZ(S,T)
                  R(S,T)=R(S,T-1)+DR(S,T)
               END IF
            END DO
         END DO
        ELSE
C
C     ESTABLISH INITIAL WAKE GEOMETRY FROM MOMENTUM THEORY
C
         DO 221 S=1,SMAX
            DO 220 T=1,NIVL
               IR=MS(1)
219            D5=W(IR)*Q1

C  CHECK TO SEE IF INFLOW AT STATION IR IS .NE. TO ZERO.
C  IF INFLOW AT IR .EQ. ZERO THEN MOVE IN TO NEXT RADIAL STATION.
C  THIS PREVENTS PROGRAM FROM CRASHING & HELPS CONVERGENCE.

               IF (D5 .EQ. 0.0) THEN
                  IR=IR+1
                  GO TO 219
               ENDIF
               DZ(S,T)=D5
               R(S,T)=RS(S)       ! INITIALISE RADIAL VORTEX POSITONS
               DR(S,T)=0.0
               IF (T .EQ. 1) THEN
                  Z(S,T)=DZ(S,T)  ! INITIALISE VERTICAL VORTEX POSITONS
                 ELSE
                  Z(S,T)=Z(S,T-1)+DZ(S,T)
               END IF
  220       CONTINUE
  221    CONTINUE
```

```
      END IF
C
C  COMPUTE VELOCITIES IN WAKE DUE TO INTERMEDIATE AND FAR WAKES
C
  230 DO 271 S=1,SMAX
         DO 270 T=1,NIVL
            DZOLD(S,T)=DZ(S,T)
            DROLD(S,T)=DR(S,T)
C
C  CALCULATE VELOCITES AT R(S,T), Z(S,T) DUE TO INTERMEDIATE AND FAR WAKES
C
            CALL VTXIF(R(S,T),Z(S,T),0,WIF(S,T),UIF(S,T))
C
C
C  VELOCITY IN WAKE DUE TO ROLLED-UP NEAR WAKE
C
            H=-Z(S,T)
            IF (OPMODL .EQ. 1) GO TO 260
            WNW(S,T)=0.0
            UNW(S,T)=0.0
            DO M=1,SMAX
               RMN=RS(M)
               CALL IRING(R(S,T),RMN,H,GS(M),DU,DW)
               WNW(S,T)=WNW(S,T)+DW
               UNW(S,T)=UNW(S,T)+DU
            END DO
            GO TO 666
260         WNW(S,T)=0.0
            UNW(S,T)=0.0
            DO M=1,SMAX
               CALL ILINE(R(S,T),RS(M),H,GS(M),DU,DW)
               WNW(S,T)=WNW(S,T)+DW
               UNW(S,T)=UNW(S,T)+DU
            END DO
666         COREB=CORE(1)
            IF (DBV .GE. 0.0 .AND. Z(1,1) .LT. DBV) COREB=CORE(2)
            IF (COREB .LT. 0.005) COREB=0.005
C
C  SELF INDUCED VELOCITY
C
            WSELF(S)=1/(4.*PI)*GS(S)*(LOG(8.0*RS(S)/COREB)-0.25)
            WIF(S,T)=WIF(S,T)+WNW(S,T)*0.5+WSELF(S)
            UIF(S,T)=UIF(S,T)+UNW(S,T)*0.5
  270    CONTINUE
  271 CONTINUE
C
C     COMPUTE VELOCITY AT A ROLLED-UP NEAR WAKE DUE TO OTHER ROLLED-UP
C     NEAR WAKES
C
      DO 305 S=1,SMAX
         WRU(S)=0.0
         DO M=1,SMAX
            IF (RS(S) .GT. (RS(M)-1.E-4) .AND. RS(S) .LT. (RS(M)+1.E-4)
     1) THEN
               DW=GS(M)/(2.0*RS(M))
              ELSE
               DW=GS(M)*(1.0/(RS(M)-RS(S))+1.0/(RS(M)+RS(S)))
            END IF
            WRU(S)=WRU(S)+DW
         END DO
C
C  COMPUTE NEW WAKE GEOMETRY
```

```
C
          Z(S,1)=((WS(S)+WIF(S,1)+WRU(S)*1/(4.*PI))*0.5+WSELF(S)*0.5)*Q1
          DR(S,1)=(US(S)+UIF(S,1))*0.5*Q1
          DZ(S,1)=Z(S,1)
          R(S,1)=DR(S,1)+RS(S)
  290     DO 300 T=2,NIVL
             DZ(S,T)=Q1*(WIF(S,T)+WIF(S,T-1))*0.5
             Z(S,T)=Z(S,T-1)+DZ(S,T)
             DR(S,T)=Q1*(UIF(S,T)+UIF(S,T-1))*0.5
             R(S,T)=R(S,T-1)+DR(S,T)
  300     CONTINUE
  305 CONTINUE
C*******************************************************
      IF (DEBUGG .GE. 2) THEN
         WRITE(NUDB,*) ' '
         WRITE(NUDB,*)' VORTEX LINE/RING GEOMETRY'
         WRITE(NUDB,*)' ITERATION NUMBER',ICOUNT
         WRITE(NUDB,899) (T,T=0,NIVL)
         DO S=1,SMAX
            ZS=0.0
            WRITE(NUDB,900) S,RS(S),(R(S,T),T=1,NIVL)
            WRITE(NUDB,901) ZS,(Z(S,T),T=1,NIVL)
            WRITE(NUDB,902) GS(S)
            WRITE(NUDB,*) ' '
         END DO
      END IF
C*******************************************************
C
C     COMPUTE NEW INDUCED VELOCITIES AT ROTOR
C
      WMAX=0.0
      ERR=0.0
306   DO 330 IR=1,MRA
         ZST=0.0
         UOLD(IR)=U(IR)
         WOLD(IR)=W(IR)
         IF (IT .EQ. 0) UOLD(IR)=0.0
C
C  VELOCITIES AT RA(IR) DUE TO INTERMEDIATE AND FAR WAKES
C
         CALL VTXIF(RA(IR),ZST,LEVEL,WIFR(IR),U(IR))
C
         W(IR)=WIFR(IR)+WB(IR)
         IF ((W(IR)*W(IR)) .GT. WMAX) WMAX=(W(IR)*W(IR))
         ERR=ERR+(W(IR)-WOLD(IR))**2
  330 CONTINUE
C
C  NO LOOP IF PESCRIBED WAKE
C
      IF (LEVEL .EQ. 1) THEN
         IT=3
         GO TO 380
      END IF
C
C     COUNT ITERATIONS AND CHECK CONVERGENCE
C
      ICOUNT=ICOUNT+1
      ERR=ERR/MRA/MRA
      EPR=EPIVEL*EPIVEL*WMAX/4.0
      IF (ERR .GT. EPR) GO TO 350
      IT=3
      GO TO 380
```

```
C
C     WEIGHT NEW VELOCITIES AND DISPLACEMENTS FOR NEXT ITERATION
C
  350 DO 360 IR=1,MRA
         FOLD=1.0-FACTIV
         W(IR)=FOLD*WOLD(IR)+FACTIV*W(IR)
         U(IR)=FOLD*UOLD(IR)+FACTIV*U(IR)
  360 CONTINUE
      IT=2
      DO 375 S=1,SMAX
         DO 370 T=0,NIVL
            DZ(S,T)=FOLD*DZOLD(S,T)+FACTIV*DZ(S,T)
            DR(S,T)=FOLD*DROLD(S,T)+FACTIV*DR(S,T)
  370    CONTINUE
  375 CONTINUE
C
C     IT=0 :FIRST ITERATION, IT=2 :PROCEEDING ITERATIONS, IT=3 :CONVERGED
C
380   IF (IT .EQ. 3) GO TO 395

      IF (ICOUNT .GT. ITERV) GO TO 396
      GO TO 70
C
395   CONTINUE
      IF (DEBUGV .GE. 1) THEN
         WRITE(NUDB,*) ' INDUCED VELOCITIES FOR VORTEX LINE/RING MODEL'
         WRITE(NUDB,*) ' RADIAL STATIONS'
         WRITE(NUDB,903) (RA(IR),IR=1,MRA)
         WRITE(NUDB,*) ' BLADE AXES'
         WRITE(NUDB,*) ' AXIAL VELOCITY'
         WRITE(NUDB,903) (W(IR),IR=1,MRA)
         WRITE(NUDB,*) ' RADIAL VELOCITY'
         WRITE(NUDB,903) (U(IR),IR=1,MRA)
         WRITE(NUDB,*) ' '
      END IF
      DO JPSI=1,MPSI
         DO IR=1,MRA
            VIND(3,IR,JPSI)=-W(IR)
            VIND(2,IR,JPSI)=U(IR)*SINPSI(JPSI)
            VIND(1,IR,JPSI)=U(IR)*COSPSI(JPSI)
         END DO
         IF (DEBUGV .GE. 2) THEN
            WRITE(NUDB,*) ' SHAFT AXES'
            PSI=FLOAT(JPSI)*360.0/FLOAT(MPSI)
            WRITE(NUDB,*) '     PSI =',PSI
            CHAR='LX'
            WRITE(NUDB,904) CHAR,(VIND(1,IR,JPSI),IR=1,MRA)
            CHAR='LY'
            WRITE(NUDB,904) CHAR,(VIND(2,IR,JPSI),IR=1,MRA)
            CHAR='LZ'
            WRITE(NUDB,904) CHAR,(VIND(3,IR,JPSI),IR=1,MRA)
            WRITE(NUDB,*) ' '
         END IF
      END DO
      IF (DEBUGG .EQ. 1) THEN
         WRITE(NUDB,*) ' '
         WRITE(NUDB,*)' VORTEX LINE/RING WAKE GEOMETRY'
         WRITE(NUDB,*)' NUMBER OF ITERATIONS',ICOUNT
         WRITE(NUDB,899) (T,T=0,NIVL)
         DO S=1,SMAX
            ZS=0.0
            WRITE(NUDB,900) S,RS(S),(R(S,T),T=1,NIVL)
```

```
          WRITE(NUDB,901) ZS,(Z(S,T),T=1,NIVL)
          WRITE(NUDB,902) GS(S)
          WRITE(NUDB,*) ' '
       END DO
    END IF

C   CALCULATE MEAN INDUCED VELOCITY
    LAMBDA=0.0
    AREA=0.0
    DO IR=1,MRA
       DA=RA(IR)*DRA(IR)
       AREA=AREA+DA
       DO JPSI=1,MPSI
          LAMBDA=LAMBDA-(VIND(3,IR,JPSI)-BETAC*VIND(1,IR,JPSI)
   1      -BETAS*VIND(2,IR,JPSI))*DA
       END DO
    END DO
    LAMBDA=LAMBDA/(FLOAT(MPSI)*AREA)
    RETURN
396  WRITE(NUDB,*) '****** SOLUTION NOT CONVERGING (INDUCED VELOCIT
   1Y) ******'
    GO TO 395

    END
C-------------------------------------------------------------------
    SUBROUTINE VTXIF(RST,ZST,LEVEL,WIF,UIF)
C
C   SUBROUTINE TO CALCULATE THE VELOCITY AT (RST,ZST) DUE TO
C   THE INTERMEDIATE AND FAR WAKES
C
    REAL UIF,WIF,UI,WI,RMN,H,DW,DU,CORE(2),KT,
   1    COREB,DBV,RST,DS,FACT,WF,UF,RIBB(8)

    INTEGER M,SMAX,N,NIVL,OPMODL,WFMODL,LEVEL

    COMMON /W1DATA/W1XX(126)

    EQUIVALENCE (W1XX(13),CORE(1)),(W1XX(40),DBV)

    COMMON /RING/ NIBV,RIBB,NIVL,FACTIV,EPIVEL,WFMODL,OPMODL,FGAMMA,
   1      ITERV
    COMMON /KTIP/KT(4)

    REAL Q1,W(30),GAMA(30),RS(10),GS(10),WS(10),US(10),DZ(10,36),
   1    R(10,36),DR(10,36),Z(10,36),WIFR(30),U(30)

    COMMON /HELICOM/Q1,W,U,GAMA,RS,GS,WS,US,DZ,R,DR,Z,WIFR,SMAX

    UIF=0.0
    WIF=0.0
    DO M=1,SMAX
       WI=0.0
       UI=0.0
C
C   INTERMEDIATE WAKE
C
       DO N=1,NIVL
          RMN=R(M,N)
          H=Z(M,N)-ZST
          IF (OPMODL .EQ. 1) THEN
             CALL ILINE(RST,RMN,H,GS(M),DU,DW) ! VORTEX LINE
            ELSE
```

```
            CALL IRING(RST,RMN,H,GS(M),DU,DW) ! VORTEX RING
          END IF
C
C  EFFECT OF VISCOUS CORE USING APPROXIMATION BY SCULLY
C
          IF (LEVEL .GE. 1) THEN
            COREB=CORE(1)
            IF (DBV .GT. 0.0 .AND. DBV .GT. Z(1,1)) COREB=CORE(2)
            DS=(RMN-RST)**2+H*H
            FACT=DS/(DS+COREB*COREB)
           ELSE
            FACT=1.0
          END IF
          WI=WI+DW*FACT
          UI=UI+DU*FACT
        END DO
C
C  FAR WAKE
C
        H=Z(M,NIVL)-ZST+DZ(M,NIVL)
        RMN=R(M,NIVL)+DR(M,NIVL)
        IF (OPMODL .EQ. 1) THEN
          CALL FLINE(RST,RMN,H,GS(M),UF,WF) ! VORTEX LINE
         ELSE
          CALL FRING(RST,RMN,H,GS(M),UF,WF) ! VORTEX RING
        END IF
        IF (LEVEL .EQ. 1) THEN                ! PRESCRIBED WAKE
          IF (WFMODL .EQ. 1) THEN             ! CONCENTRATED FAR WAKE
            IF (M .EQ. 1) THEN                ! TIP VORTEX
              GAMM=4.0*GS(M)
              IF (OPMODL .EQ. 1) THEN
                CALL ILINE(RST,RMN,H,GAMM,UF,WF) ! VORTEX LINE
               ELSE
                CALL IRING(RST,RMN,H,GAMM,UF,WF) ! VORTEX RING
              END IF
             ELSE                             ! ROOT VORTEX
              IF (OPMODL .EQ. 1) THEN
                CALL ILINE(RST,RMN,H,GS(M),UF,WF) ! VORTEX LINE
               ELSE
                CALL IRING(RST,RMN,H,GS(M),UF,WF) ! VORTEX RING
              END IF
            END IF
          END IF
          IF (WFMODL .EQ. 0) THEN             ! NO FAR WAKE
            WIF=WIF+WI
            UIF=UIF+UI
           ELSE IF (WFMODL .EQ. 1) THEN       ! CONCENTRATED FAR WAKE
            WIF=WIF+(WI+WF)
            UIF=UIF+(UI+UF)
           ELSE
            WIF=WIF+(WI+WF/DZ(M,NIVL))        ! DISTRIBUTED FAR WAKE
            UIF=UIF+(UI+UF/DZ(M,NIVL))
          END IF
         ELSE
          IF (ABS(DZ(M,NIVL)) .LT. 0.0001) DZ(M,NIVL)=0.1
          WIF=WIF+(WI+WF/DZ(M,NIVL))          ! FREE WAKE
          UIF=UIF+(UI+UF/DZ(M,NIVL))
        END IF
      END DO
      RETURN
      END
C-----------------------------------------------------------------
```

```
      SUBROUTINE IVTERP(S,I)
C
C  SUBROUTINE TO CALCULATE THE INDUCED VELOCITY AT RS(S) BY
C  INTERPOLATING THE VELOCITIES AT RA(I) (I=1,MRA)
C
      REAL RA(30),GRAD

      INTEGER S,I

      COMMON /RTR1CM/RTR1XX(1070)

      EQUIVALENCE (RTR1XX(20),RA(1))

      REAL Q1,W(30),GAMA(30),RS(10),GS(10),WS(10),US(10),DZ(10,36),
     1     R(10,36),DR(10,36),Z(10,36),WIFR(30),U(30)

      COMMON /HELICOM/Q1,W,U,GAMA,RS,GS,WS,US,DZ,R,DR,Z,WIFR,SMAX


      GRAD=(RS(S)-RA(I-1))/(RA(I)-RA(I-1))
C  VERTICAL VELOCITY
      WS(S)=WIFR(I-1)+(WIFR(I)-WIFR(I-1))*GRAD
C  RADIAL VELOCITY
      US(S)=U(I-1)+(U(I)-U(I-1))*GRAD
      RETURN
      END
C-----------------------------------------------------------------
      SUBROUTINE ILINE(R,P,H,GAMMA,UILINE,WILINE)
C
C  FUNCTION FOR RADIAL AND AXIAL COMPONENT OF VELOCITY INDUCED
C  BY VORTEX LINE
C
      REAL R,P,H,GAMMA,UILINE,WILINE
      DATA PI/3.14159265/
      IF (ABS(H) .LT. 1.E4 .AND. ABS(P-R) .LT. 1.E-4) THEN
            UILINE=0.0
            WILINE=0.0
            RETURN
      END IF
C
      WILINE=GAMMA/(2.*PI)*((P-R)/((P-R)**2+H*H)+(P+R)/((P+R)**2+H*H))
      UILINE=-GAMMA/(2.*PI)*(H/((P-R)**2+H*H)-H/((P+R)**2+H*H))
C
      RETURN
      END
C-----------------------------------------------------------------
      SUBROUTINE IRING(R,P,H,GAMMA,UIRING,WIRING)

C
C     FUNCTION FOR RADIAL AND AXIAL COMPONENT OF VELOCITY
C     INDUCED BY VORTEX RING
C
      REAL R,P,H,K2,E,K,TEMP2

      DATA PI/3.14159265/
      IF (ABS(H) .LT. 1.E-4 .AND. ABS(P-R) .LT. 1.E-4) THEN
         WIRING=0.0
         UIRING=0.0
         RETURN
      END IF
      CALL ELLIPCON(R,P,H,K2,E,K)
```

```
C
      TEMP2=K2/(R*P)
      IF (TEMP2 .LE. 0.0 ) THEN
         WRITE(6,*) ' BAD SIGN.  MODULE IRINC'
         STOP
      END IF
C AXIAL VELOCITY
      WIRING=SQRT(TEMP2)*(K-E*(1.0-.5*K2*(1.0+P/R))/(1.0-K2))
      WIRING=GAMMA/(PI*4.)*WIRING
C RADIAL VELOCITY
      UIRING=H/(2.0*R)*SQRT(TEMP2)*(E*(2.0-K2)/(1.0-K2)-2.0*K)
      UIRING=-GAMMA/(4.*PI)*UIRING
C
      RETURN
      END
C-------------------------------------------------------------
      SUBROUTINE ELLIPCON(R,P,H,K2,E,K)
C
C     EVALUATE CONSTANTS USED IN INDUCED VELOCITY COMPONENTS
C     DEFINED BY ELLIPTIC INTEGRALS
C
      REAL R,P,H,K2,E,K,TEMP2,F

      K2=4.0*R*P/((R+P)**2+H*H)
      IF (K2 .GE. (1.0-2.E-8)) GO TO 100
C
      TEMP2=1.0-K2
      F=LOG(4.0/SQRT(TEMP2))
      E=1.0+.5*(F-.5)*(1.0-K2)+3./16.*(F-13./12.)*(1.0-K2)**2
      K=F+.25*(F-1.0)*(1.0-K2)+9./64.*(F-7./6.)*(1.0-K2)**2
C
      RETURN
C
  100 E=1.0
      K=10.0
      K2=1.0-3.0E-8
C
      RETURN
      END
C------------------------------------------------------------
      SUBROUTINE FRING(R,P,H,GAMMA,UFRING,WFRING)
C
C     RADIAL AND AXIAL COMPONENT OF VELOCITY INDUCED BY SEMI-
C     INFINITE VORTEX CYLINDER
C
      REAL R,P,H,PI,P3,P4,X3,I4,K2,E,K,TEMP2

      DATA PI/3.14159265/
      IF(ABS(P) .LT. 1.0E-6) P=1.0E-6
C
C  AXIAL VELOCITY
C
      WFRING=0.0
      P3=0.2*PI
      DO 20 P4=P3*0.5,PI-P3*0.5,P3
      X3=P*P+R*R+H*H-2.0*R*P*COS(P4)
      I4=P3*P*(P-R*COS(P4))/(P*P+R*R-2.0*R*P*COS(P4))
     *     *(1.0-H/SQRT(X3))
C

      WFRING=WFRING+I4
   20 CONTINUE
```

```
      WFRING=GAMMA/(2.*PI)*WFRING
C
C  RADIAL VELOCITY
C
      CALL ELLIPCON(R,P,H,K2,E,K)
      TEMP2=P/R/K2
      IF (TEMP2 .LE. 0.0) THEN
         WRITE(6,*) P,R,K2
         WRITE(6,*) 'BAD SIGN.  MODULE FRING'
         STOP
      END IF
      UFRING=-GAMMA/(2.*PI)*SQRT(TEMP2)*(K*(2.0-K2)-2.0*E)
      RETURN
      END
C-----------------------------------------------------------------
      REAL FUNCTION FLINE(R,P,H,GAMMA,UFLINE,WFLINE)
C
C  RADIAL AND AXIAL VELOCITY DUE TO VORTEX SHEET
C
      REAL R,P,H,PI,E,GAMMA,UFLINE,WFLINE

      DATA PI/3.1415927/
C AXIAL VELOCITY
      WFLINE=PI/2.-ATAN(H/(R+P))
      IF(P .GT. (R+1.0E-8)) WFLINE=PI-ATAN(H/(P-R))-ATAN(H/(P+R))
      IF(P .LT. (R-1.0E-8)) WFLINE=ATAN(H/(R-P))-ATAN(H/(R+P))
      WFLINE=GAMMA/(2.*PI)*WFLINE
C RADIAL VELOCITY
      UFLINE=-GAMMA/(4.*PI)*LOG((H*H+(R+P)**2)/(H*H+(P-R)**2))

      RETURN
      END
C-----------------------------------------------------------------
      SUBROUTINE PRESWG(I)
C
C DETERMINES PESCRIBED WAKE GEOMETRY FOR VORTEX RING AND LINE METHODS
C
      REAL HV,RT,RROOT,KT(4),RIBB(8)
      INTEGER IR,NIVL,WFMODL
C --------------- CAMRAD COMMON BLOCKS ---------------------------
      COMMON /R1DATA/R1XX(932)
      COMMON /KTIP/KT
      EQUIVALENCE (R1XX(81),RROOT)
C ---------------------- END -------------------------------------
      COMMON /RING/ NIBV,RIBB,NIVL,FACTIV,EPIVEL,WFMODL,OPMODL,FGAMMA,
     1       ITERV
      REAL Q1,W(30),GAMA(30),RS(10),GS(10),WS(10),US(10),DZ(10,36),
     1      R(10,36),DR(10,36),Z(10,36),WIFR(30),U(30)

      COMMON /HELICOM/Q1,W,U,GAMA,RS,GS,WS,US,DZ,R,DR,Z,WIFR,SMAX

      RS(1)=1.0
      GS(1)=GAMA(I)
      RS(2)=RROOT
      GS(2)=-GS(1)
      DO IR=1,NIVL+1
         HV=KT(1)*Q1+KT(2)*(Q1*IR-Q1)
         RT=KT(4)+(1-KT(4))*(1.0/EXP(Q1*IR*KT(3)))
         R(1,IR)=RT
         R(2,IR)=RROOT
         Z(1,IR)=HV
```

```
   Z(2,IR)=HV
END DO
DZ(1,NIVL)=Z(1,NIVL+1)-Z(1,NIVL)
DZ(2,NIVL)=DZ(1.NIVL)
DR(1,NIVL)=R(1,NIVL+1)-R(1,NIVL)
IF (WFMODL .EQ. 1) THEN
   DR(1,NIVL)=1.0-R(1,NIVL)
   DR(2,NIVL)=0.0
   DZ(1,NIVL)=0.0
   DZ(2,NIVL)=0.0
END IF
RETURN
END
```

APPENDIX G
Input Description

New Variables in Namelist NLWAKE

Variable	Default	Description
OPMODL	0	Inflow model 0 vortex lattice (existing CAMRAD model) 1 vortex line 2 vortex ring
NIVL	4	Number of vortex levels in intermediate wake; maximum 36
WFMODL	2	Far wake model in prescribed wake vortex line and ring models 0 no far wake 1 concentrated 2 distributed sheet
FACTIV	0.1	Factor introducing lag in induced velocity iteration
EPIVEL	0.05	Tolerance for induced velocity
FGAMMA	0.6	Roll-up weighting factor
ITERV	200	Maximum number of induced velocity iterations
NIBV	2	Number of rolled-up vortices; minimum 2, maximum 10
RIBB(NIBV-2)		Inboard edge of rolled-up vortices from root to tip, excluding root and tip; must be between root and 0.9 (default: evenly distributed)

Comments on Important Existing CAMRAD Variables

Namelist	Variable(s)	Comment	
NLTRIM	MPSI, MPSIR	Because solutions are independent of azimuth, can be as low as number of blades	
NLTRIM	DEBUG(14),(24)	Additional debug information for new models	
		Prescribed wake	Free wake
NLTRIM	LEVEL(1)	1	2
NLTRIM	ITERU	1	0 or 1
NLTRIM	ITERR	1	0 or 1
NLTRIM	ITERF	N/A	1
NLWAKE	OPRWG	Defines prescribed wake geometry, as with existing vortex lattice model in CAMRAD	
NLWAKE	CORE(1),(2), DBV	As with existing vortex lattice model in CAMRAD	
NLWAKE	FWGT(1),(2)	For Kocurek & Tangler ($8 \leq$ OPRWG ≤ 11) and Landgrebe ($8 \leq$ OPRWG ≤ 11) models, factors for vortex settling rates KT(1) and KT(2); equal 1 for unchanged experimental rates	

APPENDIX H

Test Case Command File

```
$ASSIGN [USERNAME.CAMRAD.AIRFOIL]NACA0012.TAB AFTABLE1
$ASSIGN [USERNAME.CAMRAD.INPUT]H34.DAT INPUTFILE
$DEFINE/USER_MODE SYS$OUTPUT [USERNAME.CAMRAD]H34.OUT
$RUN [USERNAME.CAMRAD]CAMRAD
 &NLCASE NCASES=1,BLKDAT=0,NFRS=-1,NFEIG=-1,NFAF2=41,&END
 &NLTRIM MPSI=4,MPSIR=4,DEBUG(24)=1,DEBUG(14)=1,
 VKTS=0.0,FACTOR=0.5,ITERC=40,ITERM=40,FACTM=0.5,MTRIM=80,
 LEVEL(1)=1,ITERR=1,ITERF=0,DELTA=0.5,ITERU=1,
 OPDENS=3,TEMP=56.0,DENSE=0.00232,
 OPTRIM=11,EPTRIM=0.001,CTTRIM=0.0817,MHARM=0,NROTOR=1,
 COLL=9.1,
 DOF=54*0,DOFT=8*0,
 NPRNTP=0,NPRNTL=0,NPRNTT=1,NPRNTI=1,
 OPREAD=1,1,2*0,1,1,
 &END
 &NLRTR VTIPN=621.6,BTIP=1.00,KHLMDA=1.15,
 KFLMDA=1.0,FXLMDA=1.0,FMLMDA=0.,FACTWU=0.5,OPCOMP=1,
 &END
 &NLWAKE KFW=120,OPHW=0,OPRWG=8,FACTWN=0.1,
 WKMODL(2)=0,WKMODL(4)=0,WKMODL(6)=0,WKMODL(8)=0,WKMODL(12)=0,
 CORE(1)=0.05,CORE(2)=0.05,DBV=-1.,
 FWGT(1)=1.0,FWGT(2)=1.0,
 EPIVEL=0.02,WFMODL=2,OPMODL=1,NIBV=2,FGAMMA=0.7,
 FACTIV=0.1,ITERV=200,
 &END
 &NLBODY CONFIG=0,ASHAFT(1)=0,
 &END
 &NLLOAD MALOAD=1,NWKGMP=4*0,MWKGMP=0,
 NPLOT=75*0,
 &END
```

APPENDIX J
Test Case Output File

```
***********************************************************************************
*                                                                                 *
*   COMPREHENSIVE ANALYTICAL MODEL OF ROTORCRAFT AERODYNAMICS AND DYNAMICS        *
*   RELEASE ONE,  JANUARY 1980                                                    *
*                                                                                 *
***********************************************************************************


READING NAMELIST NLCASE

NEW JOB, NUMBER OF CASES =    1
RESTART FILE NOT WRITTEN  (RSWRT = 0)
INPUT SOURCE IS FILE  (BLKDAT = 0)
INPUT FILE READ EVERY CASE  (RDFILE = 1)

UNIT NUMBERS
    INPUT FILE,       NFDAT = 40      RESTART FILE,      NFRS = -1     NAMELIST INPUT,  NUIN =  5     DEBUG OUTPUT,      NUDB =  6
    AIRFOIL 1 FILE, NFAF1 = 41      EIGENVALUE FILE, NFEIG = -1     PRINTED OUTPUT, NUOUT =  6     PRINTER-PLOTS,     NUPP =  6
    AIRFOIL 2 FILE, NFAF2 = 41      SCRATCH FILE,     NFSCR = 50                                    LINEAR SYSTEMS, NULIN =  6

                   INPUT FILE,        NAME  =  [AER213.CAMRAD.INPUT]H34.DAT
                   AIRFOIL 1 FILE,    NAME  =  [AER213.CAMRAD.AIRFOIL]NACA0012.TAB


READING INPUT FILE
READING NAMELIST NLTRIM
READING NAMELIST NLRTR (ROTOR 1)
READING NAMELIST NLWAKE (ROTOR 1)
READING NAMELIST NLBODY
READING NAMELIST NLLOAD (ROTOR 1)
READING AIRFOIL TABLES
COMPREHENSIVE ANALYTICAL MODEL OF ROTORCRAFT AERODYNAMICS AND DYNAMICS
*******************************************************************************************************
CASE NUMBER   1 (NEW JOB),  IDENTIFICATION =   5  5 86  14:03:12,  CODE =       , ENGLISH UNITS (FT, SLUG, SEC)

                                                                                         (ID =   6/10/87  17:53:59)
    TITLE       =  H-34 HELICOPTER

    ROTOR 1     =  H-34 HELICOPTER MAIN ROTOR                                            (ID =   7/23/85  17:35:31)
    AIRFOIL 1 =  NACA 0012 AIRFOIL       (STANDARD C81 TABLES)
    AIRFRAME   =  H-34 HELICOPTER AIRFRAME


TRIM ANALYSIS
WIND TUNNEL TRIM,  OPTRIM = 11
SINGLE ROTOR CONFIGURATION,  NROTOR = 1
```

```
OPERATING CONDITONS
       VELOCITY (KNOTS)        =     0.00        GROSS WEIGHT          =  11900.00        ALTITUDE MSL      =      841.3
       V/(OMEGA*R)             =   0.0000        CW/S                  =   0.08665        DENSITY           =   0.002320
       VELOCITY                =     0.00        CG FUSELAGE STATION   =    0.0000        DENSITY RATIO     =     0.9756
       ROTATIONAL SPEED (RPM)  =   211.99        CG WATERLINE          =    0.0000        DENSITY ALTITUDE  =      841.4
       TIP SPEED               =   621.60        CG BUTTLINE           =    0.0000        SOUND SPEED       =    1113.22
       TIP MACH NUMBER         =   0.5584        DYNAMIC PRESSURE, Q   =     0.000        TEMPERATURE       =      56.00

       OUT OF GROUND EFFECT
       AIRCRAFT ENVIRONMENT (1 FOR ALT AND STD DAY, 2 FOR ALT AND TEMP, 3 FOR DENSITY AND TEMP),  OPDENS = 3
       WING FLAP SETTING,  AFLAP =    0.00 DEG
       ENGINE STATE (1 FOR AUTOROTATION, 2 FOR ENGINE OUT),  OPENGN = 0
       GOVERNOR TRIM (0 TO TRIM COLL, 1 TO TRIM ROTOR-1 GOV, 2 TO TRIM ROTOR-2 GOV, 3 TO TRIM BOTH GOVERNORS),  OPGOVT = 0


MAIN ROTOR PARAMETERS
       RADIUS            =    28.000       V/(OMEGA*R)             =   0.0000       OPSTLL =    1
       NUMBER OF BLADES  =       4         TIP SPEED               =   621.60       OPYAW  =    0
       LOCK NUMBER       =    9.6976       ROTATIONAL SPEED (RPM)  =   211.99       OPCOMP =    1
       SOLIDITY          =   0.06220       OMEGA (RAD/SEC)         =   22.200       OPUSLD =    2
       IB                =  1146.491       TIP MACH NUMBER         =   0.5584       INFLOW =  1 0 0 0 0 0
       MEAN CHORD/RADIUS =   0.04885                                                OPHVIB =    1  0  1

       COUNTER-CLOCKWISE ROTATION DIRECTION
       HINGED BLADE  (HINGE = 0, EFLAP = 0.0357, ELAG = 0.0357)
       NONUNIFORM INFLOW WITH FREE WAKE GEOMETRY (LEVEL = 2)


DEGREES OF FREEDOM
       DOF =  Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8,Q9,Q10      P0,P1,P2,P3,P4      BG                        (ROTOR-1)
              Q1,Q2,Q3,Q4,Q5,Q6,Q7,Q8,Q9,Q10      P0,P1,P2,P3,P4      BG                        (ROTOR-2)
              PHIF,THETAF,PSIF,XF,YF,ZF     QF1,QF2,QF3,QF4,QF5,QF6,QF7,QF8,QF9,QF10            (AIRFRAME)
              PSIS,PSII,PSIE     TGOVT,TGOV1,TGOV2                                          (DRIVE TRAIN)

       DOF =  0000000000    00000    0          (NBM = 0,  NTM = 0,  NGM = 0)
              0000000000    00000    0          (NBM = 0,  NTM = 0,  NGM = 0)
              000000    0000000000              (NAM =  0)
              000    000                        (NDM =  0)

       DOFT =    TRIM Q1,Q2,Q3,Q4    (ROTOR-1)        TRIM Q1,Q2,Q3,Q4    (ROTOR-2)

       DOFT =    0000         (NBMT = 0)              0000         (NBMT = 0)


ANALYSIS PARAMETERS
       NUMBER OF AZIMUTH STATIONS =   4
       AZIMUTH INCREMENT (DEG)  =  90.000
       NUMBER OF HARMONICS FOR ROTOR     =   0 (ROTOR-1)        0 (ROTOR-2)
       NUMBER OF HARMONICS FOR AIRFRAME  =   0 (ROTOR-1)        0 (ROTOR-2)
```

```
TRIM ITERATION

              DELO       DELC       DELS       DELP          CT/S
            THETA-FT    PHI-FT    THETA-FP    PSI-FP
             TGOVR1     TGOVR2     THETA-T

TARGETS                                                   0.081700

N = 0       0.15882    0.00000    0.00000    0.00000      0.082627
            0.00000    0.00000    0.00000    0.00000
            0.00000    0.00000    0.00000

  I=1       0.15446    0.00000    0.00000    0.00000      0.079228
            0.00000    0.00000    0.00000    0.00000
            0.00000    0.00000    0.00000

N = 1       0.15823    0.00000    0.00000    0.00000      0.082076
            0.00000    0.00000    0.00000    0.00000
            0.00000    0.00000    0.00000

N = 2       0.15799    0.00000    0.00000    0.00000      0.081750
            0.00000    0.00000    0.00000    0.00000
            0.00000    0.00000    0.00000
*************
AIRCRAFT TRIM
*************

   UNIFORM INFLOW
   WAKE/TRIM ITERATION NUMBER    1      (MAXIMUM =    1)

   NUMBER OF TRIM ITERATION =    2      (MAXIMUM =  80,  TOLERANCE =   0.00100)
   WIND TUNNEL, TRIM OPTION NUMBER  11

       FORCES                                                   CONTROL
                       TRIMMED      TARGET       ERROR                  TRIMMED                  INPUT
    ** CT/S           0.0817501   0.0817000   0.0006128 **     ** DELO     =     9.05     COLL     =     9.10 **
         CP/S         0.0059571   0.0000000   0.0000000           DELC     =     0.00     LATCYC   =     0.00
         CL/S         0.0817501   0.0000000   0.0000000           DELS     =     0.00     LNGCYC   =     0.00
         CX/S         0.0000000   0.0000000   0.0000000           THETA-T  =     0.00     APITCH   =     0.00
         CY/S         0.0000000   0.0000000   0.0000000           PSI-T    =     0.00     AYAW     =     0.00
         BETAC           0.0000      0.0000   0.0000000
         BETAS           0.0000      0.0000   0.0000000

       COLLECTIVE CONTROLS -- DELO =    9.05    TGOVR1=    0.00    TGOVR2=    0.00
       THROTTLE CONTROLS   -- DELT =    0.00    C-T   =    0.00
       AIRCRAFT CONTROLS   -- DELF =    0.00    DELE  =    0.00    DELA  =    0.00    DELR =    0.00
       ROTOR CONTROLS      -- T75  =    9.05    T1C   =    0.00    T1S   =    0.00
INDUCED VELOCITIES FOR VORTEX LINE/RING MODEL
RADIAL STATIONS
     0.23000  0.36000  0.43000  0.59000  0.68000  0.75000  0.80000  0.84000  0.87000  0.89000
0.91000  0.93000  0.95000  0.97000  0.99000
```

```
 BLADE AXES
 AXIAL VELOCITY
      0.04604  0.05129  0.05631  0.06487  0.07229  0.07325  0.07065  0.06554  0.05952  0.05364
 0.04643  0.03878  0.03527  0.04011  0.05821
 RADIAL VELOCITY
     -0.00428 -0.00627 -0.00758 -0.01063 -0.02342 -0.03661 -0.04681 -0.05471 -0.05844 -0.05929
-0.05904 -0.05675 -0.05123 -0.04448 -0.03871


 VORTEX LINE/RING WAKE GEOMETRY
 NUMBER OF ITERATIONS          18

RING/LINE LEVEL            0         1         2         3         4

VORTEX NO.   1   R=  0.99505   0.93178   0.87272   0.83788   0.81971
                 Z=  0.00000   0.01452   0.08148   0.17569   0.27666

STRENGTH OF ROLLED UP VORTEX  0.014695


VORTEX NO.   2   R=  0.62525   0.60237   0.57525   0.54890   0.52590
                 Z=  0.00000   0.11749   0.25421   0.39999   0.55391

STRENGTH OF ROLLED UP VORTEX -0.008817

TRIM ITERATION

               DELO       DELC       DELS       DELP          CT/S
             THETA-FT    PHI-FT    THETA-FP    PSI-FP
              TGOVR1     TGOVR2     THETA-T

TARGETS                                                     0.081700

N = 0         0.15799    0.00000    0.00000    0.00000      0.080704
              0.00000    0.00000    0.00000    0.00000
              0.00000    0.00000    0.00000
..
..
 INDUCED VELOCITIES FOR VORTEX LINE/RING MODEL
 RADIAL STATIONS
      0.23000  0.36000  0.48000  0.59000  0.68000  0.75000  0.80000  0.84000  0.87000  0.89000
 0.91000  0.93000  0.95000  0.97000  0.99000
 BLADE AXES
 AXIAL VELOCITY
      0.04640  0.05170  0.05676  0.06536  0.07279  0.07377  C.07115  0.06604  0.06001  0.05410
 0.04680  0.03909  0.03563  0.04060  0.05901
 RADIAL VELOCITY
     -0.00432 -0.00633 -0.00767 -0.01080 -0.02366 -0.03692 -0.04719 -0.05511 -0.05884 -0.05976
-0.05959 -0.05732 -0.05170 -0.04486 -0.03902
```

```
VORTEX LINE/RING WAKE GEOMETRY
NUMBER OF ITERATIONS          18

RING/LINE LEVEL           0         1         2         3         4

VORTEX NO.   1    R=   0.99502   0.93140   0.87218   0.83734   0.81923
                  Z=   0.00000   0.01483   0.08248   0.17743   0.27907

STRENGTH OF ROLLED UP VORTEX   0.014899


VORTEX NO.   2    R=   0.62546   0.60224   0.57487   0.54834   0.52516
                  Z=   0.00000   0.11845   0.25638   0.40349   0.55887

STRENGTH OF ROLLED UP VORTEX  -0.008939


N = 4         0.15952    0.00000    0.00000    0.00000       0.081664
              0.00000    0.00000    0.00000    0.00000
              0.00000    0.00000    0.00000
..
..
**********
INPUT DATA
**********


TRIM DATA
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    TITLE = H-34 HELICOPTER

    JOB OR CASE IDENTIFICATION,  CODE =
    UNITS (1 FOR ENGLISH, 2 FOR METRIC),  OPUNIT = 1
    ANALYSIS TASKS  0 TO SUPPRESS)
              ANTYPE(1) = 0          FLUTTER
              ANTYPE(2) = 0          FLIGHT DYNAMICS
              ANTYPE(3) = 0          TRANSIENT
    NAMELIST READ CONTROL,  OPREAD =   1  1  0  0  1  1  0  0  0  0
    DEBUG PRINT CONTROL,  DEBUG =    0    0 0 1 0   0 0 0 0 0   0 0 0 1 0   0 0 0 0 0   0 0 0 1 0
    INPUT PRINT CONTROL  (0 FOR SHORT FORM, 1 FOR LONG FORM),  NPRNTI =  1

OPERATING CONDITIONS
    AIRCRAFT SPEED (KNOTS),  VKTS =        0.00
    V/(OMEGA*R),  VEL =     0.0000
    ROTOR-1 TIP SPEED,  VTIP =     621.60
    ROTOR-1 ROTATIONAL SPEED (RPM),  RPM =     211.99
    AIRCRAFT ENVIRONMENT (1 FOR ALT AND STD DAY, 2 FOR ALT AND TEMP, 3 FOR DENSITY AND TEMP),  OPDENS = 3
    ALTITUDE ABOVE MSL,  ALTMSL =     811.3
    AIR TEMPERATURE,  TEMP =     59.00
    AIR DENSITY,  DENSE =  0.002326
    NUMBER OF ROTORS,  NROTOR =  1
    GROUND EFFECT (0 FOR OGE),  OPGRND =  0
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    ALTITUDE CG ABOVE GROUND,  HAGL =       0.00
    ENGINE STATE (1 FOR AUTOROTATION, 2 FOR ENGINE OUT),  OPENGN =  0
    WING FLAP ANGLE (DEG),  AFLAP =      0.00
    DEGREE OF FREEDOM VECTOR,  DOF =    0000000000000000  0000000000000000  0000000000000000  000000
    TRIM BENDING DEGREE OF FREEDOM VECTOR,  DOFT =    0000   0000

MOTION ANALYSIS
    NUMBER OF AZIMUTH STEPS,  MPSI =    4
    NUMBER OF HARMONICS IN ROTOR MOTION,  MHARM =    0    0
    NUMBER OF HARMONICS IN AIRFRAME MOTION,  MHARMF =    0    0
    NUMBER OF ROTOR AZIMUTH STEPS BETWEEN UPDATE OF AIRFRAME VIBRATION,  MPSIR =    4
    NUMBER OF REVOLUTIONS BETWEEN TEST OF MOTION CONVERGENCE,  MREV =    1
    MAXIMUM NUMBER OF MOTION ITERATIONS,  ITERM =   40
    TOLERANCE FOR MOTION CONVERGENCE (DEG),  EPMOTN =   0.02000
    MAXIMUM NUMBER OF CIRCULATION ITERATIONS,  ITERC =   40
    TOLERANCE FOR CIRCULATION CONVERGENCE (CT/S),  EPCIRC =  0.001000
    LAG TO IMPROVE CONVERGENCE OF MOTION ITERATION,  FACTM =     0.500

WAKE ANALYSIS
    INFLOW MODEL (0 FOR UNIFORM, 1 FOR PRESCRIBED WAKE, 2 FOR FREE WAKE),  LEVEL =  2  0
    WAKE/TRIM ITERATIONS (0 TO SKIP)
            ITERU =  1          UNIFORM INFLOW LEVEL
            ITERR =  0          NONUNIFORM INFLOW AND PRESCRIBED WAKE GEOMETRY LEVEL
            ITERF =  1          NONUNIFORM INFLOW AND FREE WAKE GEOMETRY LEVEL

TRIM ANALYSIS
    FREE FLIGHT TRIM (0-9) OR WIND TUNNEL TRIM (10-29),  OPTRIM =  11
    MAXIMUM NUMBER OF ITERATIONS ON CONTROL TO ACHIEVE TRIM,  MTRIM =  80
    NUMBER OF TRIM ITERATIONS BETWEEN UPDATE OF TRIM DERIVATIVE MATRIX,  MTRIMD =  20
    CONTROL STEP IN TRIM DERIVATIVE CALCULATION (DEG),  DELTA =    0.5000
    FACTOR REDUCING CONTROL INCREMENT,  FACTOR =    0.5000
    TOLERANCE ON TRIM CONVERGENCE,  EPTRIM =   0.00100
    GOVERNOR TRIM (0 TO TRIM COLL, 1 TO TRIM ROTOR-1 GOV, 2 TO TRIM ROTOR-2 GOV, 3 TO TRIM BOTH GOVERNORS),  OPGOVT = 0

    INITIAL CONTROL SETTINGS
            COLL    =       9.10          COLLECTIVE STICK DISPLACEMENT
            LATCYC  =       0.00          LATERAL CYCLIC STICK DISPLACEMENT
            LNGCYC  =       0.00          LONGITUDINAL CYCLIC STICK DISPLACEMENT
            PEDAL   =       0.00          PEDAL DISPLACEMENT
            APITCH  =       0.00          PITCH ANGLE THETA-FT OR THETA-F
            AROLL   =       0.00          ROLL ANGLE PHI-FT
            ACLIMB  =       0.00          CLIMB ANGLE THETA-FP
            AYAW    =       0.00          YAW ANGLE PSI-FP OR PSI-T
            RTURN   =       0.00          TRIM TURN RATE

    TARGETS FOR WIND TUNNEL TRIM
            CTTRIM =  0.081700          (CT/S OR CL/S)
            CPTRIM =  0.000000          (CP/S)
            CXTRIM =  0.000000          (CX/S)
            XTRIM  =     0.000          (X/Q)
            CYTRIM =  0.000000          (CY/S)
            BCTRIM =     0.000          (BETA-C)
            BSTRIM =     0.000          (BETA-S)
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    PRINT CONTROL FOR TRIM ITERATIONS (LE 0 TO SUPPRESS),  NPRNTT =    1
    PERFORMANCE PRINT CONTROL (LE 0 TO SUPPRESS),  NPRNTP =    0
    LOADS PRINT CONTROL (LE 0 TO SUPPRESS),  NPRNTL =    0

MAIN ROTOR DATA
---------------

    TITLE = H-34 HELICOPTER MAIN ROTOR

    RADIUS =   28.0000
    NUMBER OF BLADES =   4
    SOLIDITY =   0.06220
    LOCK NUMBER (AT STANDARD DENSITY) =     9.9400
    ROTATION DIRECTION (1 FOR COUNTER-CLOCKWISE AND -1 FOR CLOCKWISE),  ROTATE =  1
    NORMAL TIP SPEED,  VTIPN =  621.6000

AERODYNAMIC MODEL
    TIP LOSS PARAMETER,  BTIP =     1.0000
    TIP LOSS TYPE (1 FOR TIP LOSS FACTOR, 2 FOR PRANDTL FUNCTION),  OPTIP =  1
    TWIST TYPE (0 FOR NONLINEAR),  LINTW =  1
    LINEAR TWIST RATE (DEG),  TWISTL =     -8.000
    ROOT RADIAL STATION,  RROOT =     0.1600
    MAXIMUM BOUND CIRCULATION FOUND OUTBOARD OF RGMAX =     0.1600
    UNSTEADY AERODYNAMICS (0 TO SUPPRESS, 1 TO USE, 2 FOR ZERO IN STALL),  OPUSLD =  2
    INCOMPRESSIBLE AERODYNAMICS IF 0,  OPCOMP =  1

STALL MODEL
    STALL TYPE (0 FOR NONE, 1 FOR STATIC, 2-5 FOR DYNAMIC(WITH VORTEX LOADS IF ODD),  OPSTLL =  1
    YAWED FLOW (0 FOR BOTH, 1 FOR NO YAWED FLOW, 2 FOR NO RADIAL DRAG, 3 FOR NEITHER),  OPYAW =  0
    MAXIMUM DELAY ANGLE (DEG),  ADELAY =     15.000
    MAXIMUM ANGLE FOR NO STALL MODEL (DEG),  AMAXNS =     4.000
    DYNAMIC STALL PARAMETERS --                LIFT          DRAG          MOMENT
              TAU (TIME CONST)                -1.000        -1.000        -1.000
              PSIDS (DEG)                     15.000        15.000        15.000
              ALFDS (DEG)                     15.000        15.000        15.000
              ALFPE (DEG)                     12.000        12.000        12.000
              T-DSP (MAX PEAK                  2.0000        0.0000       -0.6500

INFLOW MODEL
    INDUCED VELOCITY CALCULATION
              INFLOW(1) = 1            THIS ROTOR (0 FOR UNIFORM, 1 FOR NONUNIFORM)
              INFLOW(2) = 0            OTHER ROTOR (0 FOR ZERO, 1 FOR EMPIRICAL, 2 FOR HUB AVERAGE, 3 FOR NONUNIFORM)
              INFLOW(3) = 0            WING-BODY (0 FOR ZERO, 1 FOR EMPIRICAL, 2 FOR NONUNIFORM)
              INFLOW(4) = 0            HORIZONTAL TAIL (0 FOR ZERO, 1 FOR EMPIRICAL, 2 FOR NONUNIFORM
              INFLOW(5) = 0            VERTICAL TAIL (0 FOR ZERO, 1 FOR EMPIRICAL, 2 FOR NONUNIFORM)
              INFLOW(6) = 0            OFF ROTOR DISK (0 FOR ZERO, 1 FOR NONUNIFORM)
    EMPIRICAL INFLOW CORRECTION FACTORS,  KHLMDA =     1.1500,   KFLMDA =     1.0000
    LINEAR INFLOW FACTOR FOR FORWARD FLIGHT,  FXLMDA =     1.0000,   FYLMDA =     1.0000
    LINEAR INFLOW FACTOR FOR HUB MOMENTS,  FMLMDA =     0.0000
    INTERFERENCE VELOCITY AT OTHER ROTOR,  KINTH =     0.0000,   KINTF =     0.0000
    INTERFERENCE VELOCITY AT AIRFRAME,  KINTWB =     0.0000,   KINTHT =     1.8000,   KINTVT =     0.0000
    FACTOR INTRODUCING LAG IN CT,CMX,CMY FOR INDUCED VELOCITY,  FACTWU =     0.5000
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DYNAMIC MODEL
    BENDING MODE TYPE (0 FOR HINGED, 1 FOR CANTILEVER, 2 FOR ARTICULATED),   HINGE =  0
    NO PITCH BEARING IF 1,   NOPB =  0
    STRUCTURAL COUPLING,   RCPL =     1.0000
    HINGE OFFSET,   EFLAP =     0.0357,    ELAG =     0.0357
    HINGE SPRING,   KFLAP =          0.0000,     KLAG =            0.0000
    HINGE SPRING PITCH (DEG),   TSPRNG+RCPLS*T75 =     0.00 +  0.0000 * T75
    COLLECTIVE CONTROL SYSTEM DAMPING,   TDAMPO =          0.0000
    CYCLIC CONTROL SYSTEM DAMPING,   TDAMPC =              0.0000
    ROTATING CONTROL SYSTEM DAMPING,   TDAMPR =            0.0000
    LINEAR LAG DAMPER COEFFICIENT,   LDAMPC =        1700.0000
    NONLINEAR LAG DAMPER MAXIMUM MOMENT (0. FOR LINEAR),   LDAMPM =         900.0000
    NONLINEAR LAG DAMPER, LAG RATE AT MAXIMUM MOMENT,   LDAMPR =        0.0400
    PITCH BENDING COUPLING (1 FOR INPUT, 2 TO CALCULATE, NEGATIVE FOR NO COS FACTOR),   KPIN =  1
    PHIPH =        0.00,     PHIPL =        0.00,     RPB =    0.05000,     RPH =    0.05000,     XPH =    0.05000
    BLADE MASS (IF LE 0. INTEGRAL OF SECTION MASS USED),   MBLADE =         -1.0000
    TIP MASS,   MASST =          0.0000
    TIP MASS CG OFFSET,   XIT =     0.00000
    FEATHERING AXIS RADIAL LOCATION,   RFA =    0.08000
    GIMBAL UNDERSLING,   ZFA =    0.00000
    TORQUE OFFSET,   XFA =   0.00000
    PRECONE (DEG),   CONE =        0.00
    DROOP AT T75=0. (DEG),   DROOP =        0.00
    SWEEP AT T75=0. (DEG),   SWEEP =        0.00
    FEATHERING AXIS DROOP (DEG),   FDROOP =        0.00
    FEATHERING AXIS SWEEP (DEG),   FSWEEP =        0.00
    CONTROL SYSTEM STIFFNESS INPUT (1 FOR SPRING, 2 FOR FREQUENCIES AT VTIPN),   WTIN =  2
                                          FREQUENCY                     SPRING
              COLLECTIVE                    4.500                         0.0000
              CYCLIC                        4.500                         0.0000
              REACTIONLESS                  4.500                         0.0000
    NUMBER OF RADIAL STATIONS IN BLADE MODE CALCULATION,   MRB =   40
    NUMBER OF RADIAL STATIONS FOR NUMERICAL INTEGRATION OF INERTIAL COEFFICIENTS,   MRM =   50
    TOLERANCE ON COLLECTIVE (DEG) FOR UPDATE OF MODES,   EPMODE =   0.50000
    CALCULATE NONROTATING BENDING FREQUENCIES IF NE 0,   NONROT =  0
    NUMBER OF BENDING MODE COLLOCATION FUNCTIONS,   NCOLB =   4
    NUMBER OF TORSION MODE COLLOCATION FUNCTIONS,   NCOLT =   2
    HUB VIBRATION COMPONENTS (0 TO SUPPRESS)
              OPHVIB(1) = 1            VIBRATION DUE TO THIS ROTOR
              OPHVIB(2) = 0            VIBRATION DUE TO OTHER ROTOR
              OPHVIB(3) = 1            STATIC ELASTIC DEFLECTION

SECTION AERODYNAMIC CHARACTERISTICS
    NUMBER OF AERODYNAMIC SEGMENTS,   MRA =  15
    EDGES OF SEGMENTS,   R =     0.1600   0.3000   0.4200   0.5400   0.6400   0.7200   0.7800   0.8200   0.8600   0.8800
                                 0.9000   0.9200   0.9400   0.9600   0.9800   1.0000
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	DRA	C/R	TWIST (DEG)	THETA-ZL (DEG)	XA/R	XAC/R	M-CORR LIFT	M-CORR DRAG	M-CORR MOMENT	TIP LOSS
RA = 0.2300	0.1400	0.04880	4.160	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.3600	0.1200	0.04880	3.120	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.4800	0.1200	0.04880	2.160	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.5900	0.1000	0.04880	1.280	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000

RA = 0.6800	0.0800	0.04880	0.560	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.7500	0.0600	0.04880	0.000	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.8000	0.0400	0.04880	-0.400	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.8400	0.0400	0.04880	-0.720	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.8700	0.0200	0.04880	-0.960	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.8900	0.0200	0.04880	-1.120	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.9100	0.0200	0.04880	-1.280	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.9300	0.0200	0.04880	-1.440	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.9500	0.0200	0.04880	-1.600	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.9700	0.0200	0.04880	-1.760	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000
RA = 0.9900	0.0200	0.04880	-1.920	0.000	0.00000	0.00000	1.0000	1.0000	1.0000	1.0000

SECTION INERTIAL AND STRUCTURAL CHRACTERISTICS
NUMBER OF INERTIAL STATIONS, MRI = 14

	TWIST	MASS	XI/R	XC/R	(KP/R)**2	EI-ZZ	EI-XX	I-THETA	GJ
RI = 0.0000	6.00	2.05000	0.00000	0.00000	0.000110	0.54000E+06	0.65000E+07	0.12900	0.83000E+06
RI = 0.0330	5.74	2.05000	0.00000	0.00000	0.000110	0.54000E+06	0.65000E+07	0.12900	0.83000E+06
RI = 0.0330	5.70	2.05000	0.00000	0.00000	0.000110	0.10400E+07	0.17400E+07	0.12900	0.83000E+06
RI = 0.0490	5.61	2.05000	0.00000	0.00000	0.000110	0.34700E+07	0.32100E+07	0.12900	0.83000E+06
RI = 0.0680	5.46	1.77000	0.00000	0.00000	0.000110	0.34700E+07	0.32100E+07	0.06800	0.83000E+06
RI = 0.0920	5.34	0.61200	0.00000	0.00000	0.000110	0.22300E+07	0.64000E+06	0.04800	0.31000E+06
RI = 0.0930	5.26	0.39900	0.00000	0.00000	0.000110	0.11000E+07	0.23600E+07	0.02300	0.31000E+06
RI = 0.1090	5.13	0.13100	0.00000	0.00000	0.000110	0.21000E+06	0.13900E+07	0.00600	0.15300E+06
RI = 0.1500	4.80	0.13100	0.00000	0.00000	0.000110	0.11900E+06	0.11900E+07	0.01200	0.14600E+06
RI = 0.1990	4.41	0.15700	0.00000	0.00000	0.000110	0.11900E+06	0.11900E+07	0.01600	0.13900E+06
RI = 0.2190	4.25	0.20500	0.00000	0.00000	0.000110	0.10200E+06	0.11100E+07	0.01750	0.12500E+06
RI = 0.8610	-0.89	0.20500	0.00000	0.00000	0.000110	0.10200E+06	0.11100E+07	0.01750	0.12500E+06
RI = 0.8850	-1.03	0.35400	0.00000	0.00000	0.000110	0.10200E+06	0.11100E+07	0.01750	0.12500E+06
RI = 1.0000	-2.00	[illegible]	0.00000	0.00000	0.000110	0.10200E+06	0.11100E+07	0.01750	0.12500E+06

NONUNIFORM INFLOW MODEL
VORTEX LINE MODEL IF 1, VORTEX RING MODEL IF 2, OPMODL = 2
EXTENT OF NEAR WAKE, KNW = 2
EXTENT OF ROLLING UP WAKE, KRW = 12
EXTENT OF FAR WAKE, KFW = [illegible]
EXTENT OF DISTANT WAKE, KDW = [illegible]
ROLLUP INITIAL RADIAL STATION, FRU = 0.8000
ROLLUP INITIAL TIP VORTEX FRACTION, FRU = 0.8000
ROLLUP EXTENT (DEG), PRU = [illegible]
NEAR WAKE TIP VORTEX FRACTION, FNW = 0.3000
NUMBER OF SPIRALS IN AXISYMMETRIC FAR WAKE, LHW = 30
AXISYMMETRIC WAKE GEOMETRY IF 0, OPHW = 0
NUMBER OF CIRCULATION POINTS, MRG = 15
CIRCULATION POINTS (AERODYNAMIC SEGMENT NUMBER), NG = 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

NUMBER OF INFLOW POINTS, MRL = 15
INFLOW POINTS (AERODYNAMIC SEGMENT NUMBER), NL = 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

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VORTEX CORE RADII
          CORE(1) =    0.05000           TIP VORTICES
          CORE(2) =    0.05000           BURST TIP VORTICES
          CORE(3) =    0.01000           DISTANT WAKE TIP VORTICES
          CORE(4) =   -1.00000           INBOARD TRAILED LINES
          CORE(5) =   -1.00000           INBOARD SHED LINES
VORTEX CORE TYPE  0 FOR DISTRIBUTED VORTICITY, 1 FOR CONCENTRATED VORTICITY)
          OPCORE(1) = 0            TIP VORTICES
          OPCORE(2) = 0            INBOARD WAKE

WAKE MODEL (0 TO OMIT, 1 FOR STEPPED LINE, 2 FOR LINEAR LINE, 3 FOR SHEET)
          WKMODL(1)  =  2            TIP VORTICES
          WKMODL(2)  =  0            NEAR WAKE SHED
          WKMODL(3)  =  2            NEAR WAKE TRAILED
          WKMODL(4)  =  0            ROLLING UP WAKE SHED
          WKMODL(5)  =  2            ROLLING UP WAKE TRAILED
          WKMODL(6)  =  0            FAR WAKE SHED
          WKMODL(7)  =  2            FAR WAKE TRAILED
          WKMODL(8)  =  0            DISTANT WAKE SHED
          WKMODL(9)  =  2            DISTANT WAKE TRAILED
          WKMODL(10) =  2            BOUND VORTICES
          WKMODL(11) =  3            HOVER WAKE AXIAL
          WKMODL(12) =  0            HOVER WAKE SHED
          WKMODL(13) =  3            HOVER WAKE RING

CORE BURST PROPAGATION RATE,  VELB =     0.3330
CORE BURST AGE INCREMENT,  DPHIB =      0.000
CORE BURST CRITERION (LT 0. TO SUPPRESS),  DBV =   -1.000000
SHEET EDGE TEST CRITERION (LT 0. TO SUPPRESS),  DVS =     0.100000
LIFTING SURFACE CORRECTION CRITERION (LT 0. TO SUPPRESS),  DLS =     0.500000
FACTOR INTRODUCING LAG IN CIRCULATION FOR INDUCED VELOCITY,  FACTWN =     0.1000
SUPPRESS X AND Y COMPONENTS OF INFLOW AT ROTORS IF 0,  OPVXVY =  1
NEAR WAKE OPTION WHEN CIRC INFLOW PT COINCIDE (0 FOR TWO SHEETS, 1 FOR LINES, 2 FOR SINGLE SHEET)
          OPNWS(1) =  1            SHED WAKE
          OPNWS(2) =  1            TRAILED WAKE
INCLUDE ROTATION MATRICES IN INFLUENCE COEFFICIENTS IF 1,  OPRTS =  0
BLADE POSITION MODEL FOR WAKE GEOMETRY
          OPWKBP(1) =  0            SUPPRESS INPLANE MOTION IF 0
          OPWKBP(2) =  0            SUPPRESS ALL HARMONICS EXCEPT MEAN IF 0
          OPWKBP(3) =  1            LINEAR FROM ROOT TO TIP IF 0
DEBUG PRINT CRITERION,  QDEBUG =     1000.000000

PRESCRIBED WAKE GEOMETRY
    EXTENT OF RIGID WAKE GEOMETRY,  KRWG =   96
    RIGID WAKE GEOMETRY MODEL,  OPRWG =   8
    PRESCRIBED WAKE GEOMETRY PARAMETERS
                           TIP VORTEX          INSIDE SHEET EDGE       OUTSIDE SHEET EDGE
          F1                1.000000              1.000000                1.000000
          F2                1.000000              1.000000                1.000000
          K1                1.000000              1.000000                1.000000
          K2                1.000000              1.000000                1.000000
          K3                1.000000              1.000000                1.000000
          K4                1.000000              1.000000                1.000000
```

```
VORTEX LINE AND VORTEX RING MODELS (PRESCRIBED AND FREE)
    NUMBER OF INTERMEDIATE VORTEX LEVELS,  NIVL =  4
    FAR WAKE MODEL (0 TO OMIT, 1 FOR CONCENTRATED, 2 FOR SHEET),  WFMODL=  2

    FOR FREE WAKE ONLY

    FACTOR INTRODUCING LAG IN INDUCED VELOCITY,  FACTIV =     0.1000
    TOLERANCE FOR INDUCED VELOCITY, EPIVEL =     0.0200
    ROLLED-UP VORTEX WEIGHTING FACTOR (EXCLUDINGTIP),  FGAMMA =    0.6000
    MAXIUM NUMBER OF INDUCED VELOCITY ITERATIONS,  ITERV = 200
    NUMBER OF ROLLED-UP VORTICIES,  NIBV =  2

FREE WAKE GEOMETRY
    EXTENT OF FREE WAKE GEOMETRY,  KFWG =   96
    FREE WAKE GEOMETRY MODEL,  OPFWG =    1
    WAKE MODEL (0 TO OMIT, 1 FOR LINE, 2 FOR SHEET)
              WGMODL(1)  =  1           INBOARD TRAILED WAKE
              WGMODL(2)  =  1           SHED WAKE
    VORTEX CORE RADII
              COREWG(1) =    0.00250          TIP VORTICES
              COREWG(2) =    0.10000          BURST TIP VORTICES
              COREWG(3) =   -1.00000          INBOARD TRAILED LINES
              COREWG(4) =   -1.00000          INBOARD SHED LINES
    RADIAL STATIONS FOR TRAILED VORTICITY
              RTWG(1) =     0.1000          INSIDE SHEET EDGE
              RTWG(2) =     0.4000          OUTSIDE SHEET EDGE OR TRAILED LINE
    NUMBER OF REVOLUTIONS OF WAKE BELOW POINT CALCULATING VELOCITY,  MRVBWG =    2
    GENERAL UPDATE,  LDMWG =   12
    BOUNDARY UPDATE,  NDMWG =   6    6    6    3
    WAKE VELOCITY CRITERIA
              DQWG(1) =  0.000500           NEAR WAKE ELEMENTS
              DQWG(2) =  0.000500           BOUND VORTEX
    NUMBER OF WAKE GEOMETRY ITERATIONS,  ITERWG =   2
    FACTOR INTRODUCING LAG IN DISTORTION,  FACTWG =   0.50000
    DEBUG PRINT CRITERIA
              IPWGDB(1) =     6               PRINT BEFORE GENERAL UPDATE
              IPWGDB(2) =     6               PRINT AFTER EACH ITERATION
              QWGDB     =  0.100000           PRINT VELOCITY CONTRIBUTION

AIRFRAME DATA
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.............
AIRCRAFT TRIM
.............


    NONUNIFORM INFLOW WITH FREE WAKE GEOMETRY
    WAKE/TRIM ITERATION NUMBER   2     (MAXIMUM =    2)

    NUMBER OF TRIM ITERATION =    4     (MAXIMUM =  80,  TOLERANCE =   0.00100)
    WIND TUNNEL, TRIM OPTION NUMBER  11
```

```
FORCES                                                                      CONTROL
                   TRIMMED       TARGET        ERROR                                  TRIMMED                      INPUT
** CT/S          0.0816636     0.0817000     0.0004450 **                ** DELO      =     9.14      COLL    =     9.10 **
   CP/S          0.0059463     0.0000000     0.0000000                      DELC      =     0.00      LATCYC  =     0.00
   CL/S          0.0816636     0.0000000     0.0000000                      DELS      =     0.00      LNGCYC  =     0.00
   CX/S          0.0000000     0.0000000     0.0000000                      THETA-T   =     0.00      APITCH  =     0.00
   CY/S          0.0000000     0.0000000     0.0000000                      PSI-T     =     0.00      AYAW    =     0.00
   BETAC            0.0000        0.0000     0.0000000
   BETAS            0.0000        0.0000     0.0000000

COLLECTIVE CONTROLS -- DELO =    9.14     TGOVR1=     0.00      TGOVR2=     0.00
THROTTLE CONTROLS   -- DELT =    0.00     C-T   =     0.00
AIRCRAFT CONTROLS   -- DELF =    0.00     DELE  =     0.00      DELA  =     0.00     DELR =     0.00
ROTOR CONTROLS      -- T75  =    9.14     T1C   =     0.00      T1S   =     0.00
***********
PERFORMANCE
***********

   VEL    = 0.0000 =      0.00     DPHI-F   =  0.0000 =     0.00     THETA-FT =    0.00     T75-R1 =    9.14
   Q      = 0.00000 =     0.00     DTHETA-F=  0.0000 =     0.00     PHI-FT   =    0.00     T1C-R1 =    0.00
                                   DPSI-F   =  0.0000 =     0.00                              T1S-R1 =    0.00
                                                                    THETA-FP =    0.00     T75-R2 =    0.00
   VELX   = 0.0000 =      0.00     DX-F     =  0.0000 =     0.00     PSI-FP   =    0.00     T1C-R2 =    0.00
   VELY   = 0.0000 =      0.00     DY-F     =  0.0000 =     0.00                              T1S-R2 =    0.00
   VELZ   = 0.0000 =      0.00     DZ-F     =  0.0000 =     0.00     THETA-T  =    0.00     DELF   =    0.00
                                                                    PSI-T    =    0.00     DELE   =    0.00
   VCLIMB= 0.0000 =       0.00     DDZ-F    =  0.0000 =     0.00                              DELA   =    0.00
   VSIDE = 0.0000 =       0.00                                                               DELR   =    0.00
   CW/S  = 0.0867 =   11900.0      DOMEGA   =  0.0000 =     0.00                              DELT   =    0.00

CONVERGENCE

      CIRCULATION ITERATIONS =  1          (MAXIMUM = 40,    TOLERANCE =  0.00100)

         ROTOR-1      CG/S-RMS =  0.0003262           G/E =    0.3262

      BLADE MOTION ITERATIONS =  1          (MAXIMUM = 40,    TOLERANCE =  0.02000)

AIRFRAME PERFORMANCE
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MAIN ROTOR PERFORMANCE
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   MUX =  0.0000   MUX-TPP =  0.0000    ALF-HP  =  90.00   MTIP = 0.5584   T75 =   9.14   T1S    =   0.00   T1C    =   0.00
   MUY =  0.0000   MUY-TPP =  0.0000    ALF-TPP =  90.00   MAT  = 0.5584   B0  =   0.00   B1C-HP =   0.00   B1S-HP =   0.00
   MUZ =  0.0000   MUZ-TPP =  0.0000    ALF-CP  =  90.00   P-HP =   0.00                  B1C-CP =   0.00   B1S-CP =   0.00
   L   =  0.0592   L-INT   =  0.0000
```

```
ROTOR FORCES
     SHAFT AXES
          THRUST                 CT =  0.0050795    CT/S =    0.081664     T =       11214.890
          DRAG FORCE             CH =  0.0000000    CH/S =    0.000000     H =           0.000
          SIDE FORCE             CY =  0.0000000    CY/S =    0.000000     Y =           0.000
          ROLL MOMENT            CMX=  0.0000000    CMX/S=    0.000000     MX=          -0.010
          PITCH MOMENT           CMY=  0.0000000    CMY/S=    0.000000     MY=          -0.004
          TORQUE                 CQ =  0.0003699    CQ/S =    0.005946     Q =       22865.182
     TIP-PATH PLANE AXES
          THRUST                 CT =  0.0050795    CT/S =    0.081664     T =       11214.890
          DRAG FORCE             CH =  0.0000000    CH/S =    0.000000     H =           0.000
          SIDE FORCE             CY =  0.0000000    CY/S =    0.000000     Y =           0.000
     WIND AXES
          LIFT                   CL =  0.0050795    CL/S =    0.081664     L =       11214.890
          DRAG                   CX =  0.0000000    CX/S =    0.000000     X =           0.000
     FORCE ANGLES
          SHAFT AXES                    PITCH =     0.00           ROLL =     0.00
          TIP-PATH PLANE AXES           PITCH =     0.00           ROLL =     0.00
          WIND AXES                     PITCH =     0.00

ROTOR POWER
     TOTAL                      CP=  0.0003699          CP/S=  0.0059463        P=      922.922
     CLIMB + PARASITE      CPC+CPP=  0.0000000  CPC/S+CPP/S=  0.0000000    PC+PP=        0.000
     PROFILE + INDUCED     CPO+CPI=  0.0003699  CPO/S+CPI/S=  0.0059463    PO+PI=      922.922
     INDUCED                   CPI=  0.0002920        CPI/S=  0.0046949       PI=      728.688
     INTERFERENCE            CPINT=  0.0000000      CPINT/S=  0.0000000     PINT=        0.000
     PROFILE                   CPO=  0.0000778        CPO/S=  0.0012514       PO=      194.234
     NON-IDEAL                 CPN=  0.0001139        CPN/S=  0.0018308       PN=      284.162

PERFORMANCE INDICES
     M   =  0.6921     CPI/CT    =  0.0575    L-INDUCED =  0.0592    D-ROTOR   =    0.000    D-TOTAL   =    0.000
     CDO = 0.01001     CPINT/CT  =  0.0000    L-INTEP   =  0.0000    D/Q-ROTOR =    0.000    D/Q-TOTAL =    0.000
     CDN = 0.01465     K-INDUCED=   1.1403    L-IDEAL   =  0.0503    L/D-ROTOR =    0.000    L/D-TOTAL =    0.000

ANGLE OF ATTACK (DEG) AND MAXIMUM BOUND CIRCULATION
                                  RA = 0.230 0.360 0.480 0.590 0.680 0.750 0.800 0.840 0.870 0.890 0.910 0.930 0.950 0.970 0.990
                  GMAX
     PSI =  90.  0.01570           1.9   4.1   4.6   4.1   3.6   3.5   3.7   3.9   4.2   4.5   4.9   5.3   5.4   5.0   3.8
     PSI = 180.  0.01570           1.9   4.1   4.6   4.1   3.6   3.5   3.7   3.9   4.2   4.5   4.9   5.3   5.4   5.0   3.8
     PSI = 270.  0.01570           1.9   4.1   4.6   4.1   3.6   3.5   3.7   3.9   4.2   4.5   4.9   5.3   5.4   5.0   3.8
     PSI = 360.  0.01570           1.9   4.1   4.6   4.1   3.6   3.5   3.7   3.9   4.2   4.5   4.9   5.3   5.4   5.0   3.8
```

AIRCRAFT PERFORMANCE

	ROTOR-1	ROTOR-2	TOTAL
CLIMB + PARASITE POWER	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)
INDUCED POWER	728.688 (78.95)	0.000 (0.00)	728.688 (78.95)
INTERFERENCE POWER	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)
PROFILE POWER	194.234 (21.05)	0.000 (0.00)	194.234 (21.05)
CLIMB POWER			0.000 (0.00)
PARASITE POWER			0.000 (0.00)
NON-IDEAL POWER	284.162 (30.79)	0.000 (0.00)	284.162 (30.79)
TOTAL POWER	922.922	0.000	922.922

GROSS WEIGHT = 11900.00
DRAG-ROTOR = 0.00
DRAG-TOTAL = 0.00
FIGURE OF MERIT = 0.6921

D/Q-ROTOR = 0.000
D/Q-TOTAL = 0.000

L/D-ROTOR = 0.000
L/D-TOTAL = 0.000

****
LOADS, VIBRATION, AND NOISE
****

MAIN ROTOR LOADS

BLADE AND HUB MOTION

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MAIN ROTOR LOADS

AERODYNAMIC LOADING, RADIAL STATION = 0.2300

SECTION COEFFICIENTS

	ALPHA	MACH	YAW	CL	CD	CM	CDR	CIRCULATION	G-MAX
PSI = 90.0	1.895	0.1310	1.055	0.19990	0.00848	0.00000	0.00848	0.00114	0.01570
PSI = 180.0	1.895	0.1310	1.055	0.19990	0.00848	0.00000	0.00848	0.00114	0.01570
PSI = 270.0	1.895	0.1310	1.055	0.19990	0.00848	0.00000	0.00848	0.00114	0.01570
PSI = 360.0	1.895	0.1310	1.055	0.19990	0.00848	0.00000	0.00848	0.00114	0.01570

VELOCITIES AND MOTION

	UT	UR	UP	U	PHI	THETA	LAG	FLAP
PSI = 90.0	0.2300	-0.0043	0.0464	0.2346	11.405	13.300	0.000	0.000
PSI = 180.0	0.2300	-0.0043	0.0464	0.2346	11.405	13.300	0.000	0.000
PSI = 270.0	0.2300	-0.0043	0.0464	0.2346	11.405	13.300	0.000	0.000
PSI = 360.0	0.2300	-0.0043	0.0464	0.2346	11.405	13.300	0.000	0.000

ANGLE-OF-ATTACK AND MACH NUMBER

	ALPHA-L	ALPHA-D	ALPHA-M	MACH-L	MACH-D	MACH-M	DALPHA*C/V	COSYAW
PSI = 90.0	1.894	1.894	1.894	0.1310	0.1310	0.1310	0.0000	0.9998
PSI = 180.0	1.894	1.894	1.894	0.1310	0.1310	0.1310	0.0000	0.9998
PSI = 270.0	1.894	1.894	1.894	0.1310	0.1310	0.1310	0.0000	0.9998
PSI = 360.0	1.894	1.894	1.894	0.1310	0.1310	0.1310	0.0000	0.9998

INDUCED VELOCITY AND GUST

	LX	LY	LZ	LIX	LIY	LIZ	UG	VG	WG
PSI = 90.0	0.00000	0.00432	0.04640	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 180.0	0.00432	0.00000	0.04640	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 270.0	0.00000	-0.00432	0.04640	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 360.0	-0.00432	0.00000	0.04640	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MEAN			0.05921			0.00000			

SECTION LOADING

	L/C	D/C	M/C	DR/C	FZ/C=CT/S	FX/C	MA/C	FR/C	FRT/C
PSI = 90.0	0.00550	0.00023	0.00000	0.00023	0.00534	0.00132	0.00000	0.00000	0.00000
PSI = 180.0	0.00550	0.00023	0.00000	0.00023	0.00534	0.00132	0.00000	0.00000	0.00000
PSI = 270.0	0.00550	0.00023	0.00000	0.00023	0.00534	0.00132	0.00000	0.00000	0.00000
PSI = 360.0	0.00550	0.00023	0.00000	0.00023	0.00534	0.00132	0.00000	0.00000	0.00000

SECTION LOADING

	L	D	M	DR	FZ=T	FX	MA	FR	FRT
PSI = 90.0	6.740	0.286	0.000	0.286	6.550	1.613	0.000	-0.005	-0.005
PSI = 180.0	6.740	0.286	0.000	0.286	6.550	1.613	0.000	-0.005	-0.005
PSI = 270.0	6.740	0.286	0.000	0.286	6.550	1.613	0.000	-0.005	-0.005
PSI = 360.0	6.740	0.286	0.000	0.286	6.550	1.613	0.000	-0.005	-0.005

SECTION POWER

	CP/S	CPI/S	CPINT/S	CPO/S	P	PI	PINT	PO
PSI = 90.0	0.000303	0.000248	0.000000	0.000055	0.4193	0.3435	0.0000	0.0758
PSI = 180.0	0.000303	0.000248	0.000000	0.000055	0.4193	0.3435	0.0000	0.0758
PSI = 270.0	0.000303	0.000248	0.000000	0.000055	0.4193	0.3435	0.0000	0.0758
PSI = 360.0	0.000303	0.000248	0.000000	0.000055	0.4193	0.3435	0.0000	0.0758

MAIN ROTOR LOADS

AERODYNAMIC LOADING, RADIAL STATION = 0.7500

SECTION COEFFICIENTS

	ALPHA	MACH	YAW	CL	CD	CM	CDR	CIRCULATION	G-MAX
PSI = 90.0	3.523	0.4208	2.805	0.40853	0.00908	0.00000	0.00908	0.00751	0.01570
PSI = 180.0	3.523	0.4208	2.805	0.40853	0.00908	0.00000	0.00908	0.00751	0.01570
PSI = 270.0	3.523	0.4208	2.805	0.40853	0.00908	0.00000	0.00908	0.00751	0.01570
PSI = 360.0	3.523	0.4208	2.805	0.40853	0.00908	0.00000	0.00908	0.00751	0.01570

VELOCITIES AND MOTION

	UT	UR	UP	U	PHI	THETA	LAG	FLAP
PSI = 90.0	0.7500	-0.0369	0.0738	0.7536	5.618	9.140	0.000	0.000
PSI = 180.0	0.7500	-0.0369	0.0738	0.7536	5.618	9.140	0.000	0.000
PSI = 270.0	0.7500	-0.0369	0.0738	0.7536	5.618	9.140	0.000	0.000
PSI = 360.0	0.7500	-0.0369	0.0738	0.7536	5.618	9.140	0.000	0.000

ANGLE-OF-ATTACK AND MACH NUMBER

	ALPHA-L	ALPHA-D	ALPHA-M	MACH-L	MACH-D	MACH-M	DALPHA*C/V	COSYAW
PSI = 90.0	3.514	3.518	3.514	0.4208	0.4208	0.4208	0.0000	0.9988
PSI = 180.0	3.514	3.518	3.514	0.4208	0.4208	0.4208	0.0000	0.9988
PSI = 270.0	3.514	3.518	3.514	0.4208	0.4208	0.4208	0.0000	0.9988
PSI = 360.0	3.514	3.518	3.514	0.4208	0.4208	0.4208	0.0000	0.9988

INDUCED VELOCITY AND GUST

	LX	LY	LZ	LIX	LIY	LIZ	UG	VG	WG
PSI = 90.0	0.00000	0.03692	0.07377	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 180.0	0.03692	0.00000	0.07377	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 270.0	0.00000	-0.03692	0.07377	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 360.0	-0.03692	0.00000	0.07377	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MEAN			0.05921			0.00000			

SECTION LOADING

	L/C	D/C	M/C	DR/C	FZ/C=CT/S	FX/C	MA/C	FR/C	FRT/C
PSI = 90.0	0.11589	0.00258	0.00000	0.00258	0.11508	0.01391	0.00000	-0.00013	-0.00013
PSI = 180.0	0.11589	0.00258	0.00000	0.00258	0.11508	0.01391	0.00000	-0.00013	-0.00013
PSI = 270.0	0.11589	0.00258	0.00000	0.00258	0.11508	0.01391	0.00000	-0.00013	-0.00013
PSI = 360.0	0.11589	0.00258	0.00000	0.00258	0.11508	0.01391	0.00000	-0.00013	-0.00013

SECTION LOADING

	L	D	M	DR	FZ=T	FX	MA	FR	FRT
PSI = 90.0	142.098	3.160	0.000	3.160	141.106	17.054	0.000	-0.155	-0.155
PSI = 180.0	142.098	3.160	0.000	3.160	141.106	17.054	0.000	-0.155	-0.155
PSI = 270.0	142.098	3.160	0.000	3.160	141.106	17.054	0.000	-0.155	-0.155
PSI = 360.0	142.098	3.160	0.000	3.160	141.106	17.054	0.000	-0.155	-0.155

SECTION POWER

	CP/S	CPI/S	CPINT/S	CPO/S	P	PI	PINT	PO
PSI = 90.0	0.010431	0.008489	0.000000	0.001947	14.4555	11.7645	0.0000	2.6975
PSI = 180.0	0.010431	0.008489	0.000000	0.001947	14.4555	11.7645	0.0000	2.6975
PSI = 270.0	0.010431	0.008489	0.000000	0.001947	14.4555	11.7645	0.0000	2.6975
PSI = 360.0	0.010431	0.008489	0.000000	0.001947	14.4555	11.7645	0.0000	2.6975

MAIN ROTOR LOADS

AERODYNAMIC LOADING, RADIAL STATION = 0.9900

SECTION COEFFICIENTS

	ALPHA	MACH	YAW	CL	CD	CM	CDR	CIRCULATION	G-MAX
PSI = 90.0	3.809	0.5538	2.253	0.49599	0.00953	0.00000	0.00953	0.01200	0.01570
PSI = 180.0	3.809	0.5538	2.253	0.49599	0.00953	0.00000	0.00953	0.01200	0.01570
PSI = 270.0	3.809	0.5538	2.253	0.49599	0.00953	0.00000	0.00953	0.01200	0.01570
PSI = 360.0	3.809	0.5538	2.253	0.49599	0.00953	0.00000	0.00953	0.01200	0.01570

VELOCITIES AND MOTION

	UT	UR	UP	U	PHI	THETA	LAG	FLAP
PSI = 90.0	0.9900	-0.0390	0.0590	0.9918	3.411	7.220	0.000	0.000
PSI = 180.0	0.9900	-0.0390	0.0590	0.9918	3.411	7.220	0.000	0.000
PSI = 270.0	0.9900	-0.0390	0.0590	0.9918	3.411	7.220	0.000	0.000
PSI = 360.0	0.9900	-0.0390	0.0590	0.9918	3.411	7.220	0.000	0.000

ANGLE-OF-ATTACK AND MACH NUMBER

	ALPHA-L	ALPHA-D	ALPHA-M	MACH-L	MACH-D	MACH-M	DALPHA*C/V	COSYAW
PSI = 90.0	3.803	3.806	3.803	0.5538	0.5538	0.5538	0.0000	0.9992
PSI = 180.0	3.803	3.806	3.803	0.5538	0.5538	0.5538	0.0000	0.9992
PSI = 270.0	3.803	3.806	3.803	0.5538	0.5538	0.5538	0.0000	0.9992
PSI = 360.0	3.803	3.806	3.803	0.5538	0.5538	0.5538	0.0000	0.9992

INDUCED VELOCITY AND GUST

	LX	LY	LZ	LIX	LIY	LIZ	UG	VG	WG
PSI = 90.0	0.00000	0.03902	0.05901	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 180.0	0.03902	0.00000	0.05901	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 270.0	0.00000	-0.03902	0.05901	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
PSI = 360.0	-0.03902	0.00000	0.05901	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
MEAN			0.05921			0.00000			

SECTION LOADING

	L/C	D/C	M/C	DR/C	FZ/C=CT/S	FX/C	MA/C	FR/C	FRT/C
PSI = 90.0	0.24267	0.00468	0.00000	0.00468	0.24296	0.01917	0.00000	-0.00018	-0.00018
PSI = 180.0	0.24367	0.00468	0.00000	0.00468	0.24296	0.01917	0.00000	-0.00018	-0.00018
PSI = 270.0	0.24377	0.00468	0.00000	0.00468	0.24296	0.01917	0.00000	-0.00018	-0.00018
PSI = 360.0	0.24367	0.00468	0.00000	0.00468	0.24296	0.01917	0.00000	-0.00018	-0.00018

SECTION LOADING

	L	D	M	DP	FZ=T	FX	MA	FR	FRT
PSI = 90.0	298.774	5.739	0.000	5.739	297.903	23.507	0.000	-0.226	-0.226
PSI = 180.0	298.774	5.739	0.000	5.739	297.903	23.507	0.000	-0.226	-0.226
PSI = 270.0	298.774	5.739	0.000	5.739	297.903	23.507	0.000	-0.226	-0.226
PSI = 360.0	298.774	5.739	0.000	5.739	297.903	23.507	0.000	-0.226	-0.226

SECTION POWER

	CP/S	CPI/S	CPINT/S	CPO/S	P	PI	PINT	PO
PSI = 90.0	0.018980	0.014337	0.000000	0.004649	26.3016	19.8684	0.0000	6.4431
PSI = 180.0	0.018980	0.014337	0.000000	0.004649	26.3016	19.8684	0.0000	6.4431
PSI = 270.0	0.018980	0.014337	0.000000	0.004649	26.3016	19.8684	0.0000	6.4431
PSI = 360.0	0.018980	0.014337	0.000000	0.004649	26.3016	19.8684	0.0000	6.4431

COMPUTATION TIMES

	CPU TIME (SEC)	PERCENT	NUMBER OF CALLS	TIME/CALL (SEC)
CASE	24.540	100.000	1	24.540
TRIM (TRIM)	22.710	92.543	1	22.710
FLUTTER (FLUT)	0.000	0.000	0	0.000
FLIGHT DYNAMICS (STAB)	0.000	0.000	0	0.000
TRANSIENT (TRAN)	0.000	0.000	0	0.000
LINEAR ANALYSIS (STABL)	0.000	0.000	0	0.000
LINEAR ANALYSIS (FLUTL)	0.000	0.000	0	0.000
NONUNIFORM INFLOW (WAKEC)	0.000	0.000	0	0.000
WAKE GEOMETRY (GEOMR)	0.000	0.000	0	0.000
VIBRATORY SOLUTION (RAMF)	16.930	68.989	10	1.693
ROTOR MODES (MODE)	0.110	0.448	10	0.011
ROTOR EQUATIONS (MOTNR)	3.040	12.388	16	0.190
PERFORMANCE (PERF)	0.420	1.711	1	0.420
LOADS (LOAD)	3.770	15.363	1	3.770

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16. ABSTRACT The incorporation of simplified hover wake models into the comprehensive rotorcraft analysis code CAMRAD is described and examples are given on their use. The axisymmetric models, in which vortices are represented by either straight lines or rings, are a more generalized form of the free wake models of R.T. Miller at MIT, with the wake geometry also able to be prescribed. Incorporation has allowed access to the tabular representation in CAMRAD of airfoil section characteristics as functions of angle of attack and Mach number, and has broadened the range of rotor wake models in the code to include a free wake hover model that does not have the convergence problems of the existing free wake model when used for hover.

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